MODERN BUILDING PRACTICE

AN UP-TO-DATE AND PRACTICAL WORK DEALING WITH THE DESIGN, PLANNING, CONSTRUCTION, AND EQUIPMENT OF MODERN BUILDINGS

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VOLUME II

BUILDING CONSTRUCTION

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MODERN BUILDING PRACTICE

VOL. II

BUILDING CONSTRUCTION

INTRODUCTION

A MODERN building, from its foundation to its roof, incorporates hundreds of discoveries which have been accumulated through centuries of practical experience.

The standard sizes of bricks, the methods of bonding, the construction of stone arches, the proportions of a roofing tile, the metal-framed window, the best shape for a pavement light—represent just a few of the things which have been found by experts to be ideally suited for the purpose in view.

We Have Had to Discriminate

To deal with every one of these within the compass of a single volume would require either the most superficial treatment or else a volume of unwieldy size. Therefore, it has been necessary to discriminate. Certain details of construction concern chiefly the designer or the maker of the various fittings and fixtures which are used in the actual building and in the equipment of the finished building. These, while of some interest to the craftsman, cannot from our readers' point of view be described as coming under the heading of directly useful information. Other details of construction have a distinct bearing on the processes and operations which have to be executed by the builder. Special attention has therefore been given to this section of the work.

Constructional Details

Various types of foundation and footing are described in detail, with notes as to the types of foundation most suited to special conditions.

Brick bonds and constructional methods used in connection with brick-built structures receive detailed attention. Useful data

regarding modern constructional work of all kinds will be found in this section.

The construction of walls and partitions and the various methods of wall and ceiling finishing will be illustrated, together with much useful data arranged as far as possible in tabular form for easy reference.

The various types of wood and metal casement windows will be described in detail—and here, again, the requirements of the builder have been kept in mind, rather than those of the designer and manufacturer.

Staircases and handrails, and interior fittings of all kinds for shops, banks, offices and churches, have each been dealt with by a specialist in the particular subject.

The Question of Builders' Plant and Equipment

In this volume, also, considerable space has been given to the subject of builders' plant and power-driven tools, which have now come into such extensive use in the industry.

Steel scaffolding, power- and hand-lifting appliances, concrete mixers, pumps and chutes, and pneumatic, electric and petrol-driven tools form an important part of the equipment of the modern builder. All these subjects, therefore, have been dealt with in considerable detail.

As one of the first requirements in the construction of buildings is that the necessary builders' plant and equipment shall be available on the site, we are devoting some of the early sections of this volume to a description of the various appliances of this kind which modern progress has placed at the disposal of the enterprising builder.

Modern Methods

As the keynote of this work is that it deals with the very latest practice, we believe that all our readers will appreciate the importance of modern plant and equipment being used. The builder who is content to use obsolete methods is seriously handicapped in his competition with rivals who avail themselves of modern building appliances.

One of the primary requirements in any class of building work to-day is sound construction. As has already been mentioned in the introduction to Volume I, if this can be combined with rapid execution of the work, the ideal combination is achieved. It is hoped that the information given in the present volume will assist towards this end.

LIFTING EQUIPMENT FOR BUILDERS

THE sole purpose of lifting tackle, whatever its nature, is to enable men to lift heavier loads more rapidly than is possible by their unaided efforts. Despite the advances made in such equipment, the Babylonian gin wheel is still with us, and we still refuse to accept the full advantages which can be gained by correct choice and use.

Scylla and Charybdis

Too often purchase is in the hands of those with little practical knowledge or with too great a regard for the twin gods Low Price and Discounts. Betwixt the Scylla of too high a price and the Charybdis of too low a price there is a happy mean where the builder can find appliances which, used intelligently, will make all the difference in that race for profit where all seem to be equally handicapped by wage and material costs.

The Gin and Fall

The simplest lifting device is the gin and fall. The former can be very good or very bad. The usual practice, of supply stores, is to purchase wheels and frames separately, assembling them by the use of a common black hexagon bolt and nut. Neither the material nor the method is good ; the pin should be properly made from good steel, formed with a large flat head on the one side and provided with a substantial split pin or keep on the other. In addition the pin should be drilled lengthwise to connect with a radial hole of about $\frac{1}{8}$ in., so that lubricant can be forced to where it is wanted instead of being poured promiscuously over the sides of the frame.

The writer has used ball-bearing gin wheels with excellent results, the effort necessary to raise a load being greatly reduced and the lowering speed of the empty rope increased.

Practical Notes on Fall Ropes

Fall ropes can be bought in a variety of material. The truest economy here is to purchase from one of the large rope-making combines, the smaller makers and importers being apt to use vegetable fibres which are too short to form a strong rope or lacking in that elasticity which is so essential to long life.

Ropes should be kept coiled and hung in a cool dark shed, and at the first signs of wear of the outer fibres should be renewed.

Although cheaper when bought by the coil, there is the danger of

decay. Bought as required, they are more likely to be cut from a new coil and to last the longer.

Use is now being made of gin wheels using wire rope, from a miniature power-driven winch, for loads up to 2 cwt., and once again the rope is best purchased from a large supplier.

Wire Ropes

Wire ropes should be of galvanised steel to prevent corrosion, have a factor of safety of six times their working load, and be built of a sufficient number of strands to make them flexible enough to pass easily around the wheel on which they are to be used. Failure to observe this point leads to rapid opening of the wires, but it can always be avoided by consulting the makers.

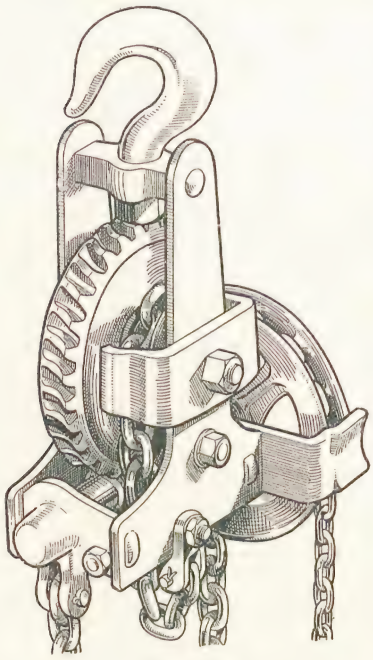


Fig. 1.—A TYPICAL PULLEY BLOCK

Thrust on the worm applies a brake automatically.

Snatch Blocks

Snatch blocks, like gin wheels, are to be bought with ball bearings. Not only do they run more freely, but they can be grease-packed before going out to a job, with the certainty that they will then be properly lubricated throughout their period of use.

What to Avoid

Too frequently base snatches are buried in debris and never cleaned or oiled, so that a plain bearing rapidly wears oval. Several fatalities have been traced to the tying down of snatches in such a way that the frame was unable to pivot and allow the rope to follow the angular changes as it laid along the winch drum. As a result, the rope was skidding on the side of the frame.

The difference in price between ball-bearing and plain snatches is so small that the former are well worth the additional outlay.

Pulley Blocks—Modern Types

For occasional lifting of heavy loads the most-used appliance is the pulley block, which can be fitted with chain, manila, or wire rope, the two latter being more suited to light loads not exceeding half a ton.

Chain pulleys may be of the spur gear, worm gear, or differential type, the latter being by far the worst in every way. All depend for their

lift on the fit of chain links in suitable recesses formed in a grooved wheel, and this fit being essential to their safety, it is well to realise the commonest cause of failure.

Chains and Their Care

Chains are constructed of links forged by hand or machine from round iron rod of such a diameter as to give sufficient tensional strength for the loads they are to lift. Each link is welded and formed in the shape of a capital O, but, being elastic, loads tend to lengthen the links, thus bringing the sides closer together.

If excessive this load will tend to crack the weld and to distort the link, so that it will no longer fit its recess and will then tend to jump. Foremen always strenuously deny that they have overloaded a tackle, but in lifting a frequent mishap is the sudden application of double the load supposedly lifted owing to its slipping from its resting position into a state of actual bearing in the sling. This is very likely to happen when picking rolled-steel sections off biats and results in unnoticed link distortion. All chain tackles and chain slings should be sent at least once a year to a qualified testing works for examination and annealing.

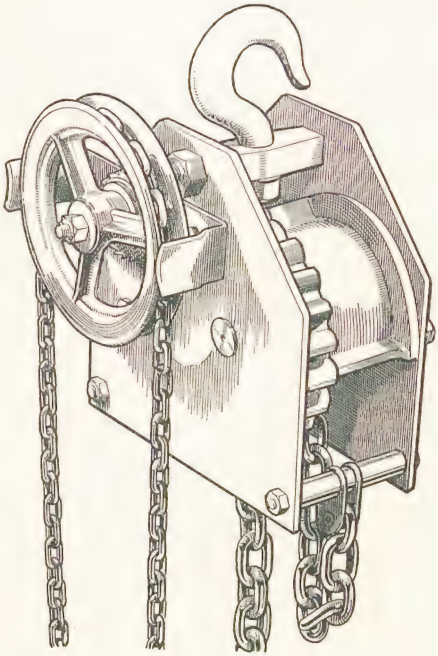


Fig. 2.—SPUR-GEARED PULLEY BLOCK

The end link of any sling should be stamped with the date of test and the working load for which it is suited, and in no circumstances should users encourage the pernicious habit of annealing by heating in a blacksmith's forge or incinerator fire. Some links will be correctly heated, but others will be too quickly cooled by accidental draughts, thus setting up unequal stresses in the metal. In addition to this only skilled men are competent to detect the earliest signs of weld or link failure.

Further Notes on the Use of Pulley Blocks

Reverting to the condemnation of the differential tackle, it is not always realised that the hand chain serves also as the lifting chain and therefore travels much farther than does the lifting chain in other types

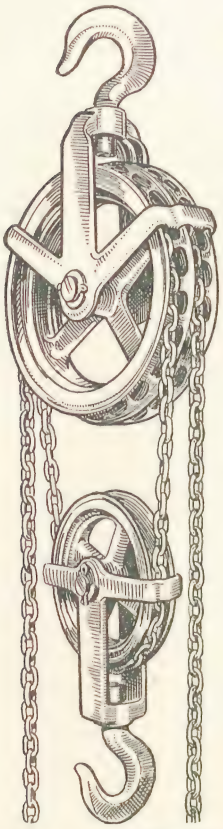


Fig. 3. — DIFFERENTIAL PULLEY BLOCK

of pulley block. This makes for rapid wear, lack of fit in the chain recesses, and consequent jumping.

Of the two types, spur gear and worm, whilst the former is very efficient and well protected from dirt in its working parts, it is high priced. Builders' pulley blocks spend so much of their lives in the plant shed that this extra cost is hardly worth while, and the worm-geared type is probably the better on an all-round view.

Complaints are frequently received of a tested worm block slipping on its first job after a test. Generally this is due to careless or over-enthusiastic lubrication, because the load is sustained by the end thrust of the drive worm being brought to bear on a leather brake pad which becomes slippery when over-oiled. A spot of petrol will cure the trouble in a few moments.

There are many cheap worm-geared blocks, but few are satisfactory. Their working loads are often marked in kilograms, which is confusing; their chains are made from low-grade iron, which has to be of excessive diameter to stand their working stresses; their frames are cumbersome; the worms and worm wheels are badly cut and sometimes even cast; they absorb too much work in friction, and, lastly, they nearly all hang badly, owing to wrong disposition of the parts, the centre of load coming to one side of the suspension hook. Without a doubt they are a bad investment.

Worm-geared Block with Gravity Lowering Device

If the best is wanted, a worm-geared block with gravity lowering device is advised, as it saves an enormous amount of time otherwise spent in lowering by hand at the same speed with which the load is picked up. The builder's requirements are best met by a two-ton block with a lift of 20 ft., this covering the normal lifting of rolled-steel breastsummers and the like.

The Wedge-lock Block

For light lifts, such as stonemason's work on cills, steps, and so on, the wedge-lock block using manila rope will be found a useful tool. The illustration shows one of these, and if preferred they can be fitted with wire rope. The return and running ropes ride over two pulleys in such a way that they nearly touch. By pulling the control cord a wedge is

lowered into the gap, where it is drawn more tightly as the load increases, thus giving a convenient holding device which allows of accurate setting of the stone.

Fig. 4.—WEDGE-LOCK PULLEY BLOCK

The hand cord actuates the wedge and locks the load.

Jacks

Jacks are essentially emergency tools. Comparatively rarely used, spending most of their life in store, they are the Cinderellas of the plant shed, yet no item of a builder's equipment needs such care in purchasing.

So many builders are motorists and have had experience of cheap car jacks, that it is difficult to understand how rapidly they forget this experience when buying a jack which may endanger the safety of a whole building or the life of a workman.

The Ship-type Hydraulic Jack

Given carte blanche by the purchasing department, the best of all jacks for the builder is probably the ship-type hydraulic. It is light, has a large flat base, is smooth in action, and has few parts likely to deteriorate in store. One objection raised to them is that they have a limited lift as compared with bottle or ratchet types, but they are so easily lowered under load that they can be packed up as the work proceeds with a minimum of difficulty and with absolute security.

Jacks can be bought which have a useful addition in the shape of a bottom foot or claw, which often enables them to be got under awkward loads, but unless the base is broad enough to bring the foot load well inside the base they are inclined to tilt and jam their bodies against the load, thus setting up a case of an "irresistible force trying to shift an immovable body."

Hoists

The use of an engine-driven winch, combined with an overhead snatch block and barrow slings, to lift concrete and the like up the face of a board apron fixed to the scaffold is, owing to the contorted but compulsory rings and the juggling necessary to land a barrow, so time-wasting that we will ignore this method and deal with the modern power platform hoists.

Power Platform Hoists

Whilst these are now familiar sights on any large building contract and can be bought in a variety of forms suited to specialised tasks, the average user knows little enough of what constitutes an efficient hoist.

The usual layout comprises a small petrol, or crude-oil, engine geared

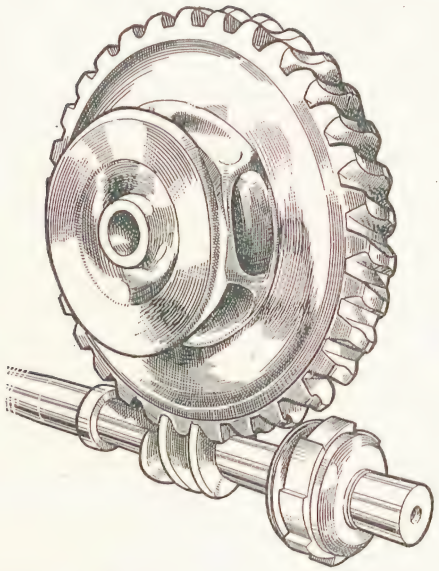


Fig. 5.—WORM-GEARED CHAIN PULLEY BLOCK.

to a winch carrying a length of steel wire rope which serves to draw a platform up suitable rails or runners attached to the scaffolding.

They may be roughly divided into two classes : those with platforms moving always in the same vertical plane; and those with rotatable platforms, which have the apparent advantage of being turnable about a vertical axis so as to swing the platform directly inwards and over the actual interior decking of the scaffold.

Practical Notes for the User

To use these latter to the best advantage needs considerable skill on the part of the driver, who, if he is not to lose time on every journey, must so handle the clutch mechanism of the winch as to bring the platform just sufficiently above, but not too high above, the landing at which he is aiming, as to avoid collision when the platform is swung around inwards and/or a dangerous impact when he lowers the platform from its too high position to a state of rest on the scaffold.

As a platform with one or two loaded wheelbarrows might weigh around 15 cwt., impact is not an over-estimated danger, particularly with modern forms of grip connections on steel tubing, whatever it might be with the older but more resilient pole scaffold.

Any advantages accruing to a landing inside the scaffold would seem to be offset by the danger of obstruction on what is usually a traffic-congested path.

In lowering the platform it becomes necessary first to raise it, then swing it outwards, then lower ; three actions cannot be performed as rapidly as one and, as will be seen later in this section, it is possible to avoid both this lost time and the obstruction difficulty by the use of other forms of hoist.

Selecting a Power Hoist

Such rotating platform machines as are sold in this country are usually of the central mast type, the mast being constructed of tube, channel, or other convenient rolled-steel section, the mast being provided with a flat metal base to give a firm support. Care should be taken to

see that if a mast hoist is purchased its base is of such a shape as to allow the platform to come level or nearly level with the ground when at its lowest point. Some Continental hoists come to rest as far as 2 ft. 6 in. above ground level, necessitating the use of timber ramps, up which the loaded wheelbarrows must be wheeled, or the use of a pit in which the base can be set. Difficulties in the way of drainage, attention to the base snatch block, and the steep angle at which the haulage rope runs to the winch drum make this an extremely unhandy design which is best avoided.

Another difficulty with badly designed central masts is that the platform frame being guided in its vertical movement by rollers running on the mast, a considerable danger of side swing exists. With a 6-in. mast, wear of as little as $\frac{1}{4}$ in. at the rollers can be magnified at the edge of a 5-ft. platform to several inches. If the hoist runs sideways to the scaffold, as is often the case, a barrow wheel passing from staging to platform can exert a wedging action which will force a gap of as much as 9 in., with dangerous results.

In the non-rotating type of platform use is made of rail sections in convenient lengths, varying from 9 ft. to 16 ft., each section being built of two parallel tees serving as actual rails, and two tees or channels serving as support members, joined at intervals by C-shaped forged pieces at distances of about 5 ft.

This form provides good resistance to swaying and bending, a wide track or gauge for the roller guides thus preventing side swing of the platform and allowing easy assembly by suitable fish-plates.

In choosing between makes which use different-weight sections, it is better to decide on the heavier one, as the sections are often subjected to severe strains whilst being transported from job to job.

Setting up a Power Hoist

Fixed platform hoists can be set up in a variety of ways: back to the scaffold; sideways; facing it, or inside an independent tower. If set back on, it is necessary to cantilever platforms at each scaffold stage for the taking off of the loads, and for this reason alone it seems better to set the hoist to run sideways-on, the only objection being that wheelbarrows must be wheeled on to the platform at the bottom and *reversed*, so that the handles present themselves conveniently for drawing off at the top. This avoids the need for men walking round the barrow on the platform which, in addition to being contrary to Home Office regulations, has resulted in several fatalities.

A small wood chock nailed to the floor of the platform will serve as a guide stop for the wheels and prevent barrow handles being left protruding beyond the line of the scaffold.

The independent tower has the advantage that men can get all round the platform; that there is no obstruction to the staging; that the

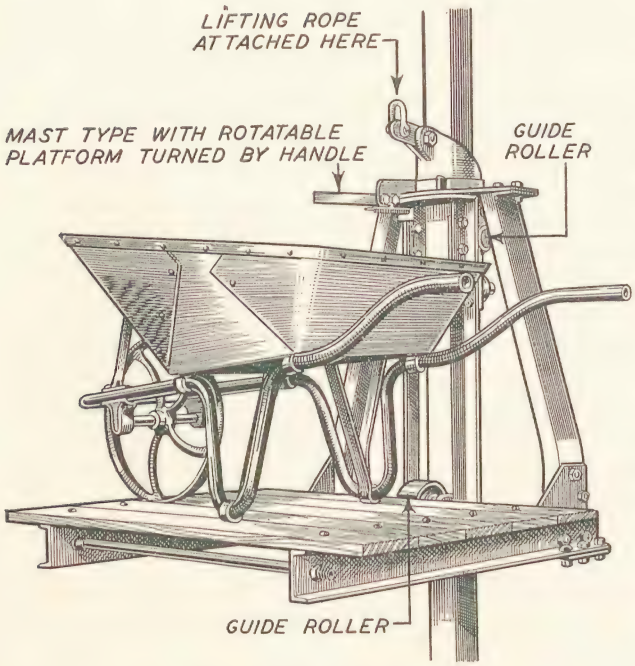


Fig. 6.—MAST TYPE HOIST
With rotatable platform turned by a handle.

scaffolding can be removed at any time without interfering with the hoist.

Notes on the Power Unit

Having decided on the best type of mast or rail and platform, attention should be given to the choice of motive power.

This may be steam, compressed air, electric or internal-combustion engine, the latter being the usual. Decision as to the best type of internal-combustion engine may be assisted by a study of several hoist makers' catalogues, the almost universal recurrence of one particular name being an indication of its qualities.

The Petrol Engine

The four-stroke engine is probably superior to the two-stroke, the parts being sturdier and its action more familiar to the average builder's employee. Its petrol-air mixture is also less liable to fluctuation. Ball or roller bearings should be insisted on for the main bearings at least, the fine grit and dust inseparable from builders' work being fatal to white-metal linings. Nothing but disappointment can follow neglect of this point.

For small hoists, with engines up to and including 9 h.p., the petrol engine has the advantage of simplicity, which makes the fuel economy of the so-called Diesel engine a problematic saving despite the low cost of fuel oil as compared to petrol. The latter is readily obtainable in any part of the United Kingdom, and in the standard 2-gallon cans presents no difficulties in the way of storage or compliance with Home Office regulations.

The Diesel Engine

Fuel oil for compression ignition, that is, Diesel or semi-Diesel engines, must be purchased in bulk, but where a hoist is to carry loads of one or

one and a half ton or over the fuel saving is considerable, and where users can be dead certain of rapid repair service, Diesels are satisfactory. The fuel-injection pump, which forms the most important part of these engines, is sealed by the maker, and even if it were not, is so accurately constructed and assembled that its repair calls for skill far beyond that of even a good driver. This fact will be appreciated when it is realised that at each stroke it must deliver a portion of fuel approximating in size to the head of a pin and that any variation either way means trouble.

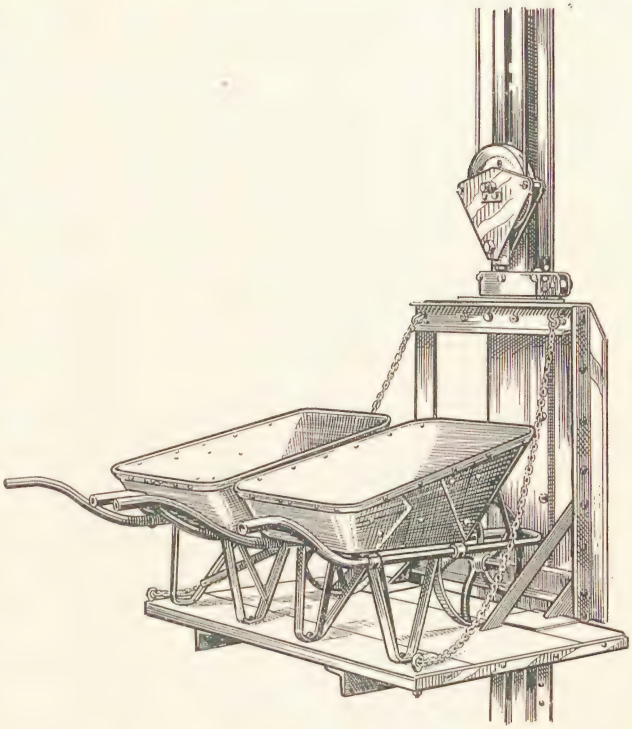


Fig. 7.—ROTATABLE TWO-BARROW PLATFORM
Note the two-part rope giving double load but halved speed of lift.

A Note on Fuel

Before leaving the question of fuels, it should be pointed out that near-petrol mixtures are not satisfactory as a rule as a substitute for petrol. The saving of even sixpence a gallon is too often lost, owing to break-downs due to sooted sparking-plugs.

Operating Notes

As the only time a hoist is a nuisance is when broken down, every care should be taken to avoid such contingencies. The loss of time by the men depending upon the hoist is serious, but not so serious as an interruption in the placing of concrete in an important load-carrying beam. Foremen are still to be found who prefer the centuries-old but reliable gin wheel and fall, owing to some bitter experience of this sort.

Without exception, every engine driver should be given half an hour's overtime after every working period for the purpose of allowing thorough cleaning and lubrication of his charge. Due attention should be given

to Saturdays, when the twelve o'clock whistle seems to have an overpowering effect. Despite the adage concerning whitened sepulchres, a clean engine is usually free from trouble.

Periodical Inspection

The contractor's engineer or plant superintendent should make a thorough inspection each month, as men are often afraid to report incipient trouble for fear of being blamed for what may be fair wear and tear.

Steam and Compressed Air

Steam and compressed air as motive powers are more usual on very large contracts carried out by engineering firms whose technical staff is too competent to need advice from outsiders, but electric drive is becoming popular enough with smaller firms to merit some attention.

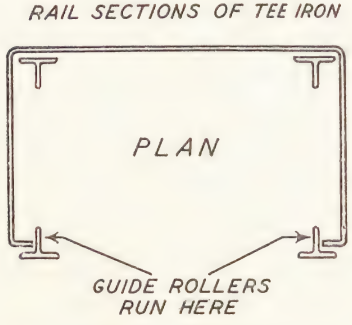


Fig. 8.—IN NON-ROTATING TYPES OF PLATFORMS USE IS MADE OF RAIL SECTIONS

Electric Drive

Its advantages are extreme freedom from break-down and reduced maintenance, but in adopting it care must be taken to see that current can be procured at a low price. Special power circuits are necessary and in some districts the charges are high. There is at the present moment some talk of regulations forbidding the use of higher working voltages than 100, which will need care in the selection of a suitable motor.

The Power Transmission

The next point of importance concerns the drive from the engine to the winch drum. This combines a gear reduction with a clutch for disengaging the power. The former may be by worm, spur gear, belt, chain and chain sprocket, or by some type of friction drive.

Whilst the latter can also be made to serve as a clutch by separation or contacting of the frictional surfaces, the four methods first mentioned necessitate the use of a separate clutch. These are of car form, in which a Ferodo-lined male member is forced into a coned female, or an expansible male member arranged to rotate inside a recess in the female. In the not unlikely event of uneven wear on the linings, the male member becomes eccentric, and when entered throws serious side strains on the bearings of the female. The need for ball-bearing thrusts, pivot pins, take-off springs and similar small parts adds to the complication and likelihood of trouble if neglected, as is almost always the case.

Friction drive may consist of a small pinion of iron, with surface grooved to marry with grooves in another iron wheel integral with the

winch drum, the smaller pinion being engine-driven by chain or spur gear wheel; or of a Ferodo, asbestos, horn, hide, paper, or cork and leather pinion similarly driven.

Whilst iron to iron gives a satisfactory coefficient of friction, it is not as popular as it was, which seems to show that it has objections. With a properly made cork pinion users are sure of smooth engagement with good resistance to wear, a life of five or six years being not uncommon.

Ferodo has a slightly better coefficient of friction. Cork frictions must be very strongly made to exert sufficient pressure on the laminations to avoid disintegration. Cork is sometimes interleaved with leather, but this does not seem to be more than a pandering to popular fancy.

The success of cork drive has long been established, whilst the fear of crumbling due to moisture is disproved by several instances of long accidental submersion under water and subsequent recovery undamaged.

Declutching is very simply carried out with a minimum of parts by mounting the winch drum axle in eccentric bearings, which can be partially rotated and so moved in a longitudinal direction by means of a short lever to which is attached a simple hand rope carried from the winch through a snatch block to a similar snatch block tied at the top of the scaffold. By this means the lever can be moved from any scaffold stage, thus giving complete control of the hoist.

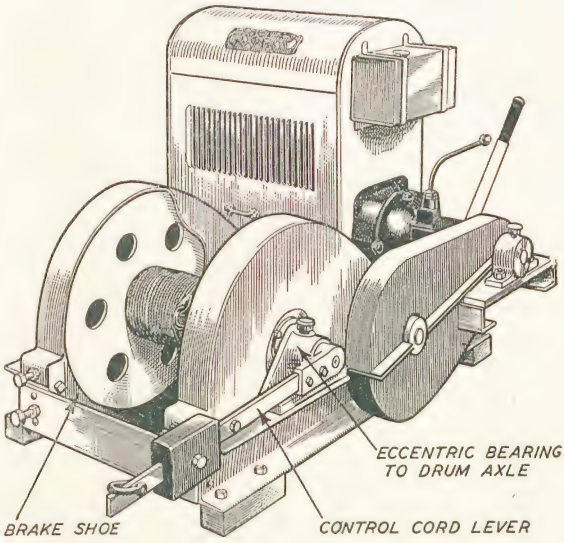


Fig. 9.—TYPICAL EXAMPLE OF A PETROL-ENGINE-DRIVEN WINCH FOR HOISTS

Pulling upwards on the lever moves the winch drum towards the engine-driven cork friction wheel, thus taking up the drive, whilst a counterweight on the lever serves to return the lever and drum away from the friction wheel and towards suitable Ferodo or wood brake blocks. Accidental release of the control cord through carelessness or illness thus applies the brakes automatically. In a good hoist the whole movement of the drum does not exceed $\frac{1}{4}$ in., thus giving extreme rapidity and certainty of hoist movement.

Safety Precautions on Large Hoists

Large hoists above 15 cwt. can be fitted with safety catches on the platform frame to avoid a fall in the event of the main rope breaking. In view of the high-quality rope generally fitted, this is a most unlikely occurrence, but when fitting a new rope to a hoist, which should be done as soon as one shows wear, a really good-quality rope must be chosen. It should be of steel wire, with the wires properly laid to prevent unravelling under load, and the diameter of the snatch wheel at the base of the hoist should always be stated, so that the suppliers can dispatch a rope of sufficient flexibility, a point which is often neglected.

The wear of a rope is determined by the rule that, if it shows more than 10 per cent. of broken wires in a length of eight diameters, it is unsafe. One end of the rope should be obtained seized, and the other end bent and seized to an eye, which is hooked to the platform frame if used single, or to the top of the mast or rail if used double, whilst the plain, seized end passes to the fastening clip on the winch drum.

The winch should never be placed nearer than 6 ft. from the base snatch wheel, as it would feed rope to the drum at such an angle as to give danger of overwinding instead of laying on coil against coil. If overwound, there is bound to be trouble through jerking as the platform is lowered and the coils slip back into place.

Specialised Hoisting Gear

In place of the usual flat wooden platform, hoists may be fitted with a tipping skip of a quarter- or half-yard capacity.

The skips being mounted on pivot pins or built with rack teeth to engage with curved racks, can be loaded, run up to the required staging level, and there tipped into a storage hopper of several yards' capacity, having a controlled outlet door through which the loads can be released into barrows, etc., as required.

In excavation work the hoist rails can be set up from the bottom of the pit and carried sufficiently high to allow of tipping into an improvised timber storage hopper arranged for discharge into the rubbish carts. With increase of capacity, these latter are becoming unfortunately much higher sided, with resultant difficulty in shovel loading.

Traversing Hoists

Another type of hoist allows a load to be raised vertically and traversed horizontally by the type of winch described in the preceding paragraphs, whilst preserving the advantages of one-man lever control. Unlike a crane, it can cover a very wide area without the need for a long space-demanding jib, the horizontal rails being standard, rolled-steel sections, easily suspended by clips from existing scaffolding.

It is of course impossible to give figures of working costs for any hoist,

unless the factor Amount of Use is known, but the following figures from an actual job may be of assistance :—

Cost £180. Depreciation at 5-year life, plus interest, £22 10*s*. Repairs £2. Petrol £19 5*s*. Lubricating oil £3 6*s*. Driver £70 3*s*. 8*d*. Transport to and from job £1 16*s*. 6*d*. Erection 10*s*. Loads raised (mechanical counting register) 11,532 mixed concrete, bricks, roofing slates, etc., or a cost of approximately 2*d*. per load.

Real satisfaction will only be obtained from a hoist if strict account is kept of its performance. Any driver, given a slate and pencil, will take a pride in finding out how much his charge has done, and the writer has not the slightest doubt but that a hoist will prove to be one of the finest investments the modern builder can make.

Portable Cranes

In addition to the platform hoist, builders have recently been offered the choice of several small cranes which are particularly adapted for lifting through small distances.

The majority of them consist of a rectangular metal base about 4 ft. by 3 ft. suitably braced to sustain a king post or upright which may vary from 5 ft. to 7 ft. in height. Attached to this is a light jib arm, with a brace running to the lower end of the king post, the whole forming a short jib crane. On the rear end of the base is a metal engine house containing a water-cooled petrol engine and suitably driven winch.

The control is by lever from the front of the engine cover, allowing the operator to see the load throughout its travel.

And Their Uses

Fitted with a tipping gowk or bucket, they are seen to best advantage in excavation work for foundations, pipe lines, etc., and if fitted with an extension to the king post, as is easily done, they will raise a load, swing it over a hoarding, and dump it into tip carts at a speed far beyond any other appliance.

Cranes are usually considered to be beyond the requirements of the average builder, but they are so adaptable as to be almost a better investment than the platform hoist.

Their ability to swing full circle about the king post enables them to reach into the most inaccessible places, whilst their light weight, combined with the ease with which they can be stripped into several separate parts, allows of their being placed at the top of a building without the slightest danger to the structure or the need for extra bracing or supports.

Choosing a Crane

In choosing such a crane, the essential feature is stability, to remove the slightest risk of overturning. Provided that this is established by

an actual demonstration on rough ground, such as is usually met with, instead of a flat concrete floor which is the salesman's choice, none of the makes at present on the market has any weakness. With a well-made engine, repairs and petrol consumption are negligible, whilst its small size makes it easy to transport from job to job.

QUESTIONS AND ANSWERS

What should be borne in mind when purchasing Wire Ropes for Lifting Tackle ?

(1) The wire should be of galvanised steel.

(2) The strand of rope should be flexible enough to pass easily round the smallest wheel on the tackle.

(3) The rope should be capable of sustaining a weight equal to six times the maximum working load.

When would you use a Chain Pulley Block in preference to Wire Rope or Manila ?

For dealing with loads in excess of half a ton.

What precaution must be observed in connection with Chain Tackles and Slings ?

They should be sent to a testing works for examination and annealing at least once a year.

What is the Wedge-lock Block ?

A form of pulley block provided with a control cord and lever, by means of which a wedge can be inserted into the gap between the return and running ropes, so as to lock the load in any desired position.

What are the four possible ways of setting up a Fixed Platform Hoist ?

(1) Back to scaffold.
(2) Sideways to scaffold.
(3) Facing the scaffold.
(4) Inside an independent tower.

What is the advantage of using an Independent Tower ?

This offers no obstruction to the staging, and the scaffolding can be removed without interfering with the hoist.

MODERN FLOOR COVERINGS

MODERN floors, with the possible exception of those employed in certain types of domestic work, are usually of reinforced concrete or other fireproof construction. Such floors require a finishing to render them suitable for use, and for this purpose a large number of different materials is available which it is convenient to classify generally as semi-permanent and permanent.

Semi-permanent Floors

Under the first heading may be grouped those coverings which after a lapse of time will probably need renewal, the most important of which are rubber, wood blocks, cork, linoleum, and various compositions of these materials.

Permanent Floors

Under the second heading may be included all those floors which when laid are so done in a manner that should render their life equal to that of the building itself; these are stone, tile, marble, mosaic, and terrazzo, and possibly the various types of magnesite composition floors.

While most of the permanent floors are easy to lay, requiring only good materials and the usual practice of good construction, the materials of the semi-permanent class present each their own special difficulty, and satisfactory results can be obtained only by a careful study of the requirements of each type.

SEMI-PERMANENT FLOORS

Rubber Flooring

This material is much used in banks, commercial offices, public buildings, and hospitals. It is noiseless, non-slipping, soft to the tread, does not harbour dust or dirt, and is also one of the most durable of the semi-permanent floors under ordinary foot traffic. It is, however, unsuitable for kitchens, or where oil or fat is likely to be spilt on it.

Types of Rubber Flooring

The rubber is supplied either in strips or tiles, the former known as "drum cured," the latter as "pressed" rubber, the terms indicating the methods employed in the final process of vulcanisation. Strip flooring, which is generally $\frac{3}{16}$ in. thick, is supplied in rolls 3 ft. to 4 ft. wide and

Fig. 1.—ONE OF THE QUICKEST METHODS OF SMOOTHING THE SURFACE OF WOOD BLOCK FLOORS IS BY MEANS OF AN ELECTRIC SANDPAPERING MACHINE

Full details regarding the laying of various types of floor coverings will be found in Volume III, which deals with builders' materials and operations.

can be had in plain or marbled tints. Some types of this flooring are manufactured in widths up to 6 ft., but the pattern is similar to that of tile floors. Rubber tiles can be obtained in a variety of thicknesses from $\frac{3}{16}$ in. to $\frac{3}{8}$ in. and in sizes from 6 in. to 24 in. square.

Special shapes can be had for covering stair treads and for angle coverings, and where they are to be used on concrete stairs the architect should carefully simplify the mouldings to the shape and size of one of the many standard types.

Good rubber flooring, whether in strips or tiles, should have the following qualities: it should be smooth, non-porous, and when bent double for a period of six hours should neither break nor crack.

Laying a Rubber Floor

In laying a floor on concrete the utmost care must be taken to ensure that the concrete is absolutely dry. Many failures are attributable to the fact that the rubber has been laid too soon on an apparently dry screed and that the damp in the concrete floor has later worked up to the surface and destroyed the mastic adhesion. In all cases the screed should be not less than 1 in. thick, and where the concrete is laid directly on the earth an asphalt or other damp-course is essential.

The Adhesive

The most common adhesives used are casein cement and ordinary rubber benzine solution, but casein will not remain in a usable condition longer than one day and must be freshly made each time. Casein cement forms a mechanical joint with the screed already laid on the concrete and when dry is very tenacious, but it has no adhesive power while damp, and rubber tiles laid with it must be held in place and the edges kept from curling with weights for some twelve hours after laying. The tiles should not be laid close to one another but a little distance apart and gently pushed into place, as this allows for the casein cement to be squeezed between the joints, thus holding the edges as well as the backs and leaving only a hair line visible between them.

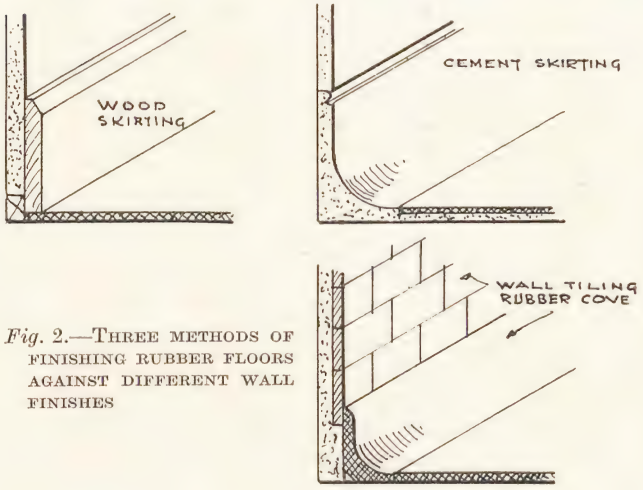


Fig. 2.—THREE METHODS OF FINISHING RUBBER FLOORS AGAINST DIFFERENT WALL FINISHES

When tiling is laid in rubber benzine solution, each tile becomes practically immovable immediately it touches the mastic. Rubber solution adheres best to a screed when the proportion of cement to sand is large, and a good mixture is 1 of cement to $2\frac{1}{2}$ of sand. An even better screed has been tried composed of 1 part of cement to $1\frac{3}{4}$ parts of coarse sawdust. This is well mixed dry and when ready for use is made into a paste with the addition

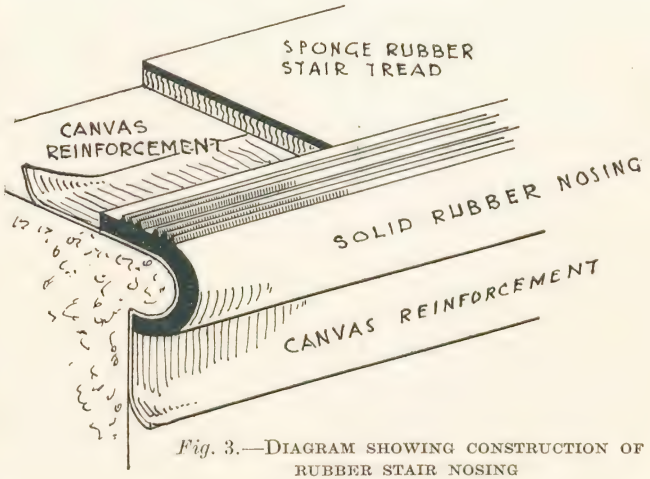


Fig. 3.—DIAGRAM SHOWING CONSTRUCTION OF RUBBER STAIR NOSING

Fig. 4.—SECTION OF RUBBER-COVERED ASBESTOS TILE

of water. Before laying the mastic the surface is scoured to remove the cement film which trowelling has brought to the top.

On wood underflooring the best results are obtained with rubber benzine solution, but on new flooring, however good, no rubber should be applied until the initial shrinkage of the boards has taken place. A worn wood floor must be planed smooth and all projecting knots levelled before applying the mastic, as any projection under the surface will cause an uneven wear in the rubber.

Special rubber and asbestos tiles in sizes from 3 in. by 3 in. to 12 in. by 12 in. are made, some having the asbestos exposed on the under side, which can be laid in ordinary cement; others having an asbestos core and normal rubber surface but the under side covered with a special keyed rubber pad which ensures rigidity in fixing; the total thickness is $\frac{3}{8}$ in. Normally, bitumen or asphalt undercoating on the concrete floor is unnecessary with this type of floor, and the hard asbestos core prevents the irregularities of old work showing through. A special rubber coving about 2 in. radius makes a clean joint at the walls, or a cement cove allowing for the thickness of the rubber may be worked on the cement screed.

For basements or sub-ground floors where moisture is present, a paving block can be had which consists of a rubber case filled with concrete. This is bedded down on to ordinary liquid grouting. The principle of this rubber block is that the rubber case is shaped to form a mechanical lock independent of any adhesion between the two materials, and the serration of the face of the rubber in contact with the concrete filling prevents the surface from creeping under continuous traffic. A more detailed treatment of the operations involved in laying rubber and other types of flooring will be found in Volume III, which deals with Builders' Materials and Operations.

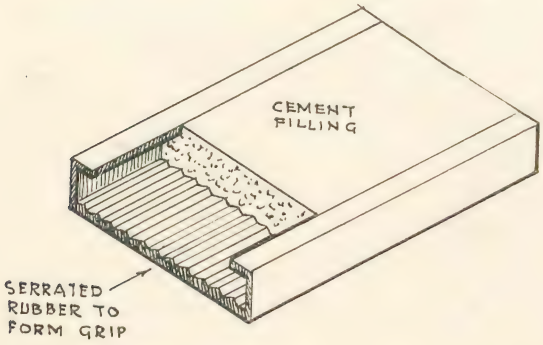


Fig. 5.—CEMENT AND RUBBER TILE SHOWING UNDER SIDE

Normal Thicknesses for Different Types of Buildings

Rubber flooring, to be successful, must be laid in sufficient thickness to stand up to the expected wear, but an extra-thick floor does not always mean a better floor. The follow-

ing are the normal thicknesses for different types of buildings: domestic buildings, $\frac{1}{8}$ in. to $\frac{3}{16}$ in. thick; shops and public buildings, $\frac{1}{4}$ in. to $\frac{3}{8}$ in. thick.

In ordering rubber for staircases the following simple rules should be observed:—

Give number of steps, and sketches showing full size of any winders.

Size of landings.

Depth of tread from face of riser to front of nosing.

Thickness of nosing, and the projection. (A cardboard template is best.)

Height of riser to under side of nosing.

State if rubber is to be full width of stairs.

And give thickness required. (Usually $\frac{1}{4}$ in.)

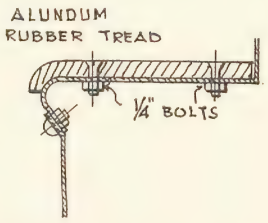


Fig. 6.—ALUNDUM RUBBER TREAD ON IRON STAIRS

Linoleum

The basis of linoleum is a more or less equal mixture of boiled linseed oil and cork dust, pressed on a canvas backing under heat with the pattern either surface printed or inlaid. Printed linoleums will not stand up to hard wear without the pattern wearing off but are less expensive than inlaid, in which the powder is pressed through stencils on to the canvas backing thus ensuring that the design and colours go right through the thickness of the material. Ruboleum, as the name implies, contains a certain amount of rubber.

Linoleum, unlike rubber, will break off " short " if bent backwards on itself and is therefore unsuitable for sharp angles. When cut to size it should be allowed to lie loose for a short time before gluing down, especially if it is to be closely fitted to breaks and angles. Linoleum will not adhere to damp concrete and it is a better practice to lay first a strip of cork underlay in hot bitumen. This underlay need not be thicker than $\frac{5}{32}$ in., so that the total thickness of linoleum, mastic cement and cork will be about $\frac{3}{8}$ in., the usual thickness of a good-wearing linoleum being $\frac{1}{8}$ in. This cork will not only add resilience to the floor and lengthen its life but also obviate the possibility of failure through damp rising from the concrete floor.

A somewhat similar material known as linovent is made for covering wood flooring under linoleum. This is a bituminous base coated with cork granules which takes up any unevenness of the floor boards, an important point as these will in time lead to a

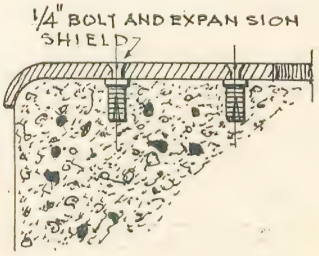


Fig. 7.—ALUNDUM RUBBER SAFETY STAIR TREAD

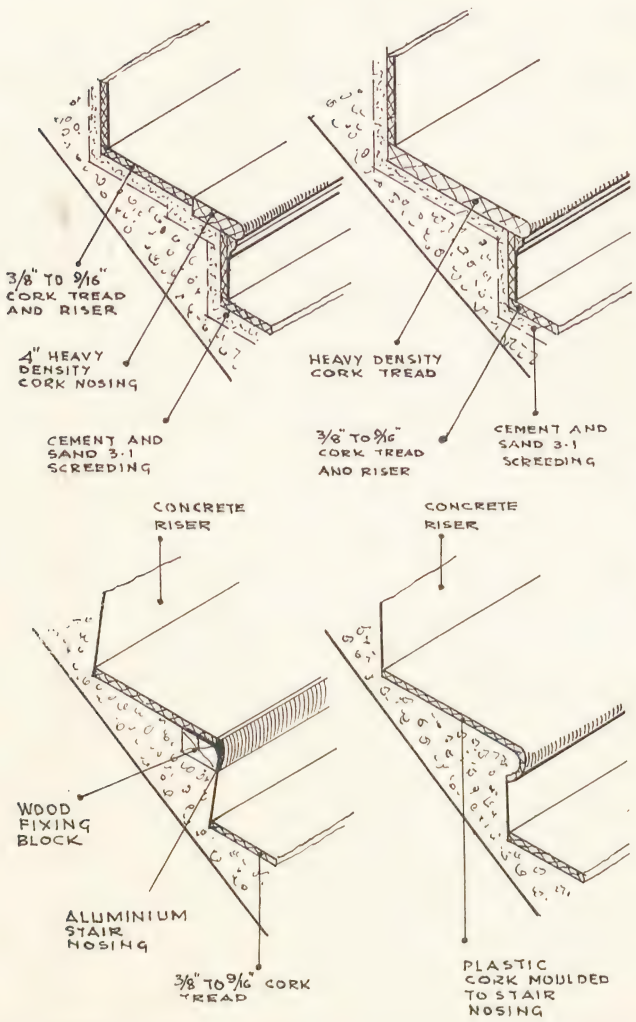


Fig. 8.—FOUR METHODS OF FIXING CORK TILING ON CONCRETE STAIRS

cracking in the linoleum if laid directly upon them. Many firms now supply linoleum cut into tiles, which allows a floor to be designed in different colours similar to rubber tiling. This method is wholly satisfactory as long as the difference between the two materials is kept in mind. It is therefore best to finish a linoleum floor against a cement coved skirting.

Cellular Rubber

A special material of the rubber type is now available which consists of a cellular sponge under side with a sheet of solid rubber about $\frac{1}{16}$ in. thick vulcanised on to it, the whole forming a carpet about $\frac{3}{4}$ in. thick. This is suitable for hospitals and places where silence coupled with extreme cleanliness is essential. Concrete staircases covered with this type of rubber are very resilient to the tread and stand up to a remarkable amount of hard wear. Special nosings are supplied which will cover the projections of old stone or concrete steps.

Alundum Safety Tread

This aluminium oxide product, which is the basic ingredient in all non-slip floorings, can now be had moulded into specially hard and tough

replaceable rubber stair nosings. The rubber is vulcanised so as to be of good resilience and the alundum is incorporated in the whole tread, including the curved nosing. With this type of non-slip tread there are no grooves or projections to retain dust and dirt. This alundum impregnated rubber is employed in factory floors round machinery, and in workhouses. It is also useful for bathroom floors, where accidents can happen on the wet, slippery flooring.

Granwood

This flooring material is a hybrid between magnesite and wood block flooring, although the material is without any actual magnesite compound. The blocks, 6 in. by 2 in. by $\frac{5}{8}$ in., composed of compressed wood dust and a proprietary compound are similar to, but smaller than, wood blocks. These can be laid in cement on ordinary screeding in a variety of colours, and when finished polished with any of the ordinary floor polishes. This floor does not require a floated sub-floor but merely ruling off the concrete with a wood rule 1 in. below the finished floor level. This material is claimed to be vermin- and insect-proof, a good non-conductor of electricity, and is without expansion and contraction under temperature changes.

Cork

Cork has been mentioned as an underlay for linoleum, but it can also be used to form a pure cork parquet floor. The material is composed of clean cork curlings compressed under heat until the liquefaction of the natural gums in the bark form a cementing mastic without the addition of any adhesive. The tiles thus made are from $\frac{3}{8}$ in. to $\frac{9}{16}$ in. in thickness and can be had in almost any size up to as large as 36 in. by 12 in., but 12 in. by 12 in. is a satisfactory unit for most purposes. No colouring matter is added, but the shades may vary from tile to tile through several tones of rich brown. Coved angles about 2 in. by 2 in. form the best finish against walls. The cork is made in two qualities : ordinary, and heavy density, the latter suitable for stair nosings and other places liable to very hard traffic. (See Fig. 8.)

In preparing the sub-floor a screed of 1 to 5 Portland cement and sand $\frac{1}{2}$ in. minimum thickness should be spread, finished with a wood float, and on this the tiles are laid in mastic and sometimes with "invisible" nails. After fixing, the surface is gone over with a sanding machine which leaves it smooth and ready for polishing. Cork tiles were tested at the National Physical Laboratory in 1929 in comparison with oak, and the following abrasion figures were recorded. Under the sand test the oak surface wore away ·13 in. and the cork tile ·08 in.

Wood Block Floors

This type of floor consists of sawn wood bricks laid in a bituminous mastic on a concrete base. As with all adhesive floor coverings—and a

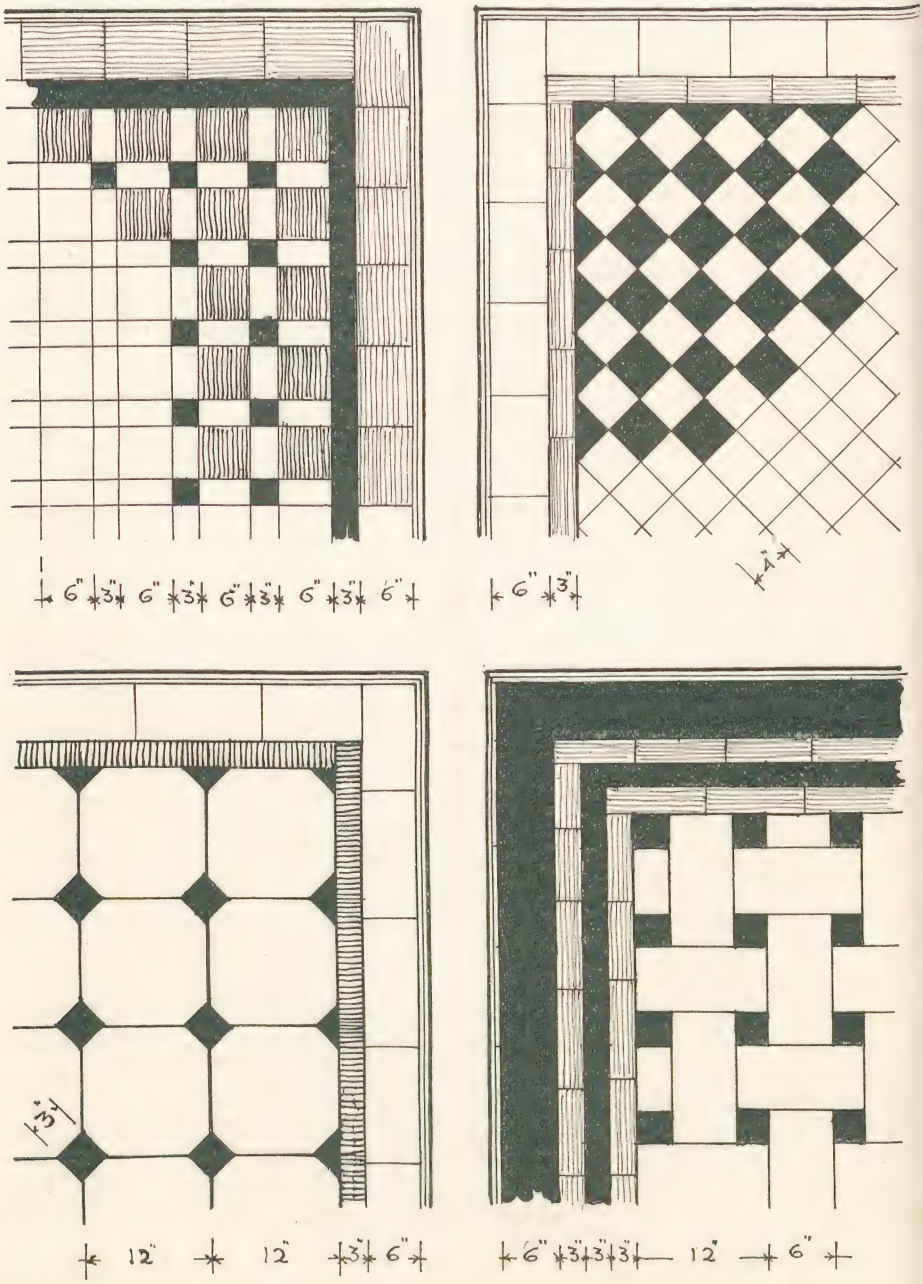


Fig. 9.—SOME TYPICAL DESIGNS FOR CORK OR RUBBER TILE FLOORING

wood block comes under this heading—the proper preparation of the sub-floor is of the utmost importance. The concrete and the cement screed laid upon it for the reception of the mastic must be bone dry. Often in the haste of modern building the desire to speed things up betrays a contractor into too early laying on a floor that appears to be sufficiently dry. A wind will carry off the damp from plastered walls with such rapidity that they appear dry, but a humid day will find the same walls running with moisture and the atmosphere inside the building charged with water to saturation point. It is therefore wise to leave the laying of the wood block flooring until the windows are glazed, the building entirely weatherproof and, if possible, until the heating system is in operation.

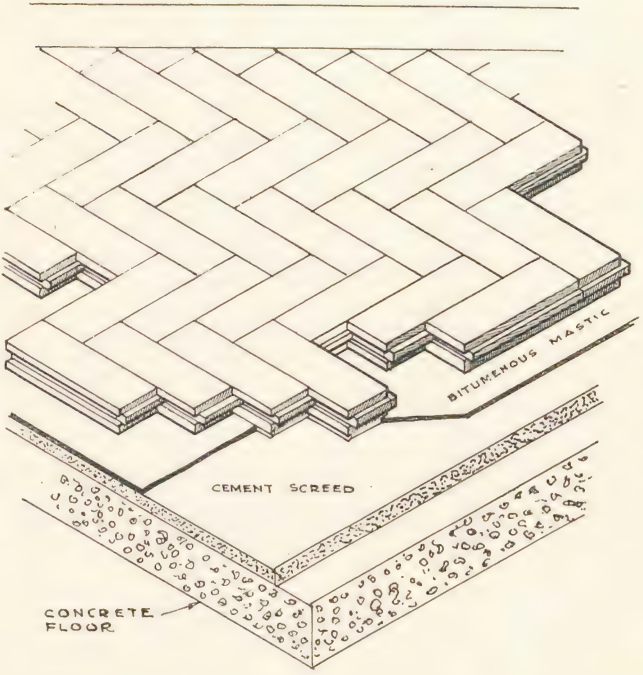


Fig. 10.—METHOD OF LAYING WOOD BLOCKS ON CONCRETE FLOOR

Before beginning to lay the blocks the sub-floor should be swept clean, and the screeding treated with creosote to lay the dust and assist the mastic to adhere. The mastic usually employed is a mixture of pitch and coal-tar boiled together in specially designed baths, and the blocks are carefully dipped in this and then placed in position. First-class firms are particularly careful over the composition of their mastics and frequently have them specially blended, for the adhesive should remain permanently pliable without being " tacky " and must not set hard like ordinary pitch or it will become brittle and give way. An inferior mastic is easily broken either by a slight movement of the blocks or by a sudden powerful blow.

Blocks Must Be Dry

The pattern commonly adopted is a herringbone with a margin two or three blocks wide laid parallel to the walls, but the design can be

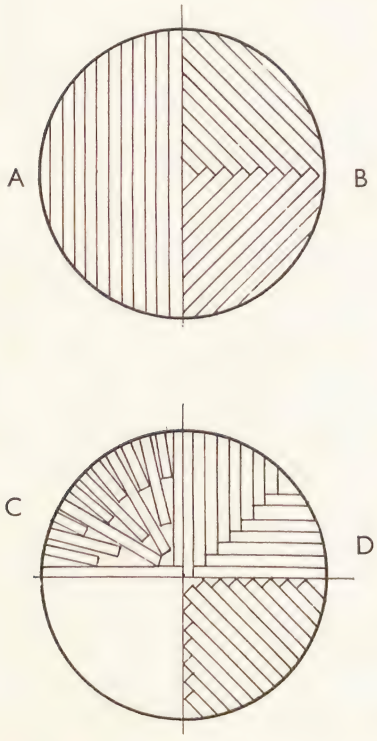


Fig. 11.—DIAGRAM SHOWING HOW TIMBER IS CUT UP

A and B, alternative methods of obtaining slash or flat-sawn timber. C, True rift sawn; D, cut on the quarter.

varied indefinitely at slightly increased cost. The blocks themselves must be dry and their storage when received on the job should be as carefully considered as that of cement bags. It is obviously of little use to delay laying the floor in order to dry out the screeding if the blocks already delivered are stacked in a damp shed.

All kiln-dried blocks are liable to slight shrinkage and swelling, but the movement should not be sufficient to cause the floor to bulge over a large area. When the movement does not occur until some time after the floor has been in use the failure is usually due to an abnormal cause. In one case where every care had been taken a floor suddenly bulged after about two months, and it was found that the blocks had been laid in exceptionally dry weather, and that an excessive amount of water had subsequently been used in cleaning the floor.

To avoid lifting it is a usual practice to allow for expansion when laying. Where the floor finishes against a wood skirting the blocks should be laid with a space all round the wall, which is afterwards covered with the skirting board. In an unplastered room or one with a cement skirting it is a usual practice where there is any risk of swelling to omit laying the wood block margins until the work is finished and possibly even until the floor is cleaned off.

"Equivalent Moisture Control"

This is a phrase frequently met with in connection with the seasoning of woods. It represents the moisture content to which a timber will absorb water when subjected to certain temperature and humidity conditions; it is in fact the static condition of a floor in a building when the humidity has reached the normal level usual for occupation. The danger period is immediately after laying, when the abnormal dampness from plastering, etc.

Fig. 12.—SHOWING DISTORTION OF SLAB-SAWN OAK DUE TO MOISTURE ABSORPTION

may be absorbed by the kiln-dried blocks. It is therefore important to select a wood with a low " Ratio of Expansion," which means the degree to which the wood will swell after absorbing a given amount of moisture.

How Wood Blocks are Manufactured

Wood blocks are usually manufactured tongued and grooved or straight jointed, both types having a small dovetailed fillet along the sides at the lower edge. There is also a dowelled block on the market in which the blocks are fixed together with short wooden dowel pins. Tongued and grooved blocks are no guarantee that the floor will not lift ; they will, however, prevent individual blocks from coming loose and rattling.

Hardwood tongued and grooved blocks are usually $\frac{7}{8}$ in. finished thickness, having a wearing surface above the tongue of $\frac{7}{16}$ in. Some architects feel that $\frac{7}{8}$ in. finish is too shallow and specify $1\frac{1}{8}$ in. hardwood straight-jointed blocks, but the practice is wasteful, for by the time $\frac{7}{16}$ in. is worn off the surface of any floor it will require relaying, no matter how deep the actual thickness of the block may be.

Softwood blocks should be $1\frac{1}{8}$ in. finished thickness rift sawn. (See Fig. 11.)

Quartered Oak

" Quartered " oak or beech will remain more stable than " plain sawn " because the annual rings of growth run straight down from the surface to the under side of the blocks, and swelling is greater in the direction of the rings than radially, thus the expansion will be proportionally greater in the thickness than in the width of the block. In practice softwoods are considered " rift sawn " when the annual rings run at an angle of not less than 45 degrees when cut across the grain at the end of the block.

Amongst the woods most commonly employed for floor blocks may be mentioned—

Maple, Birch, Douglas Fir, Kauri Pine, Malai, Teak, Pynkado, Oak, Beech, Gurjun, Tasmanian Oak and Jarrah. These are all woods from within the Empire and will suffice for most purposes in modern building.

Noel Floor

Another type of wood floor with a totally different method of laying is the Noel floor. Hardwood blocks $4\frac{3}{8}$ in. by 1 in. by $\frac{3}{8}$ in. are laid in a special oxychloride cement designed to give great adhesion and sufficient elasticity to take up the expansion and contraction of the wood. The blocks are bedded in a similar manner to tiles, leaving a joint showing the bedding material between each block. The finished thickness of block and bedding is $\frac{1}{2}$ in. These floors, it is claimed, will, under normal conditions, set and be ready to take traffic in from 12 to 24 hours. After the floor is surfaced with a special electric surfacing machine it is ready to take any of the usual floor polishes.

TEMPORARY TIMBERING

UNDER this heading would be included all timber work necessary to support the sides of trenches, shores to walls undergoing alterations, centres for arches and formwork in which concrete is cast until it sets.

Timbering for Trenches

Shallow trenches, say, 2 ft. in depth, suitable for the footings of small house property, will seldom require to have their sides supported by timber. If the foundation concrete is cast within a reasonable time of the trench being opened it will give the necessary support. See Fig. 1.

Fig. 2 shows timbering for a trench in moderately firm ground. The struts of all trenches should be at least 6 ft. apart so that workmen have the necessary working room. In moderately firm ground, apart from the dangers due to vibration caused by heavy traffic, the work of excavation should be fairly straightforward, but loose sand or waterlogged soils may offer difficulties.

Pressure on Timbers

According to the nature of the soil, so the pressure on the revetting materials varies. In other words " the angle of repose " for different soils affects the pressure on the retaining timbers. A trench in firm ground will, at least when first cut, throw little pressure on the timbers, but if the trench be kept open for any length of time it will soon begin to crumble, and lumps will break away unless it is timbered.

Ordinary Soil

The line AB in Fig. 3 might be taken to represent " the angle of repose " for ordinary soil, i.e., if a heap of the soil were thrown up, the surface would lie at that angle. The wedge-shaped portion marked A would therefore exert pressure against the timber.

Loose Sand Soil

Suppose the soil to be loose sand, line BC might be the angle of repose, and the combined pressure of the wedges A and B would be thrown against the timbers.

Wet Sand

Again, suppose the sand to be wet, and CD the angle of repose, a little

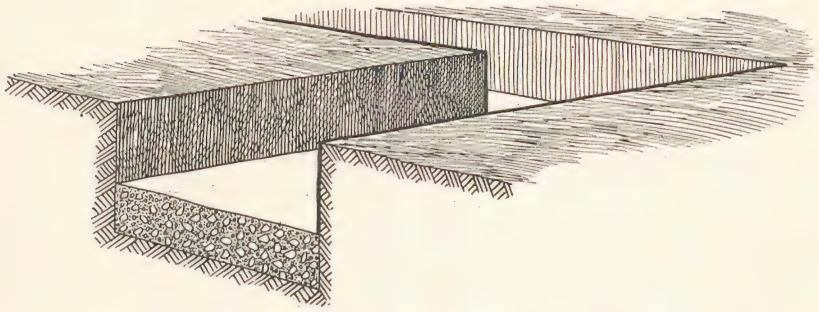


Fig. 1.—SHALLOW TRENCHES, SUITABLE FOR THE FOOTINGS OF SMALL HOUSE PROPERTY, SELDOM REQUIRE TIMBER SUPPORTS

If the foundation concrete is cast within a reasonable time of the trench being opened, it will give the necessary support.

more pressure is added by the wedge C. The nearer the soil approaches to a liquid condition the greater will the pressure become until it is governed by the laws for liquids. The formation of the ground and the time for which the trench must be left open will govern the amount of support necessary.

TYPES OF TIMBERING

Trench for Drains

Fig. 4 shows a trench such as might be required for a drain, and the ground is assumed to be of a loose nature. As the trench is cut, horizontal boards are laid against the sides with temporary struts wedging them apart. Temporary struts and "poling boards" should be placed in such a position that they will not interfere with the final pieces being fixed. When the depth is reached upright pieces (poling boards) are placed as shown with a strut at top and bottom.

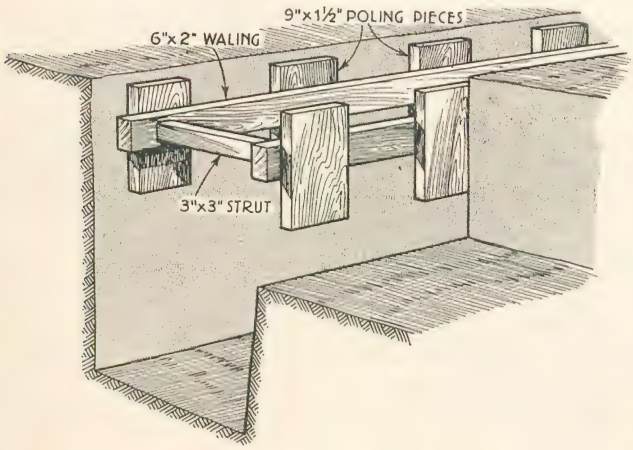


Fig. 2.—TIMBERING FOR A TRENCH IN MODERATELY FIRM GROUND

Trench for Sewer

A deeper trench such as might be

required for a sewer is shown in Fig. 5, and again the ground is loose and requires close boarding. As the ground is excavated temporary struts keep the sides from caving in and these are replaced as soon as possible by "sheeting" and horizontal battens (walings).

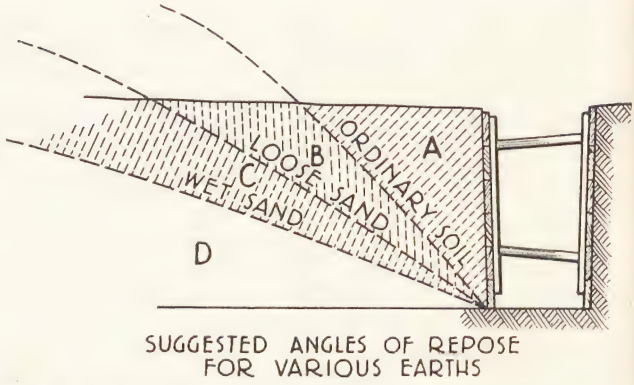


Fig. 3.—THE NATURE OF THE SOIL AFFECTS THE PRESSURE ON THE RETAINING TIMBERS

The nearer the soil approaches to a liquid condition the greater will the pressure become.

The "spoil" from a trench can be thrown clear of the edge from a depth of 5 or 6 feet, but for lower levels some arrangement must be provided to enable this to be done. A platform (as suggested in Fig. 5) is provided by laying boards on the temporary struts of the top section. The earth from the lower part is thrown on the platform, and from there to the surface. If the trench has to be still deeper it is carried down by successive stages in the same manner.

Trench for Waterlogged Soil

Fig. 6 illustrates a method of dealing with loose sand or waterlogged soil. The edges of the boards are shaped to fit (Fig. 6A) and the points cut on the slope. As the trench is excavated the boards are driven down

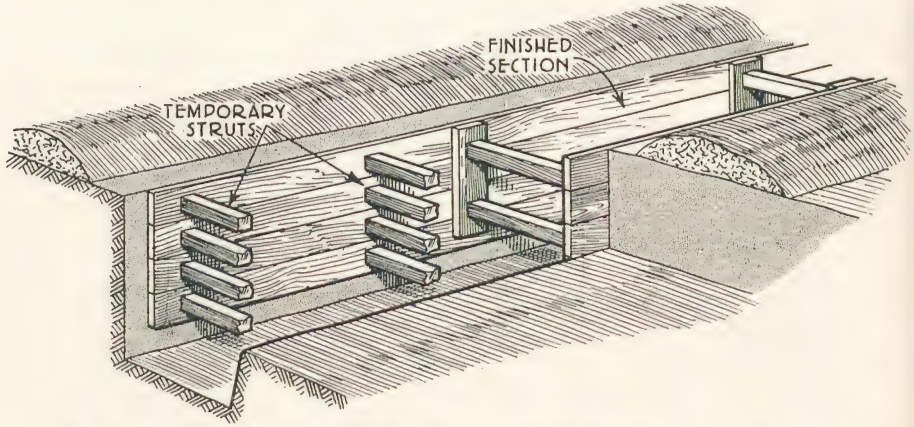


Fig. 4.—TIMBERING FOR A TRENCH FOR A DRAIN IN GROUND OF A LOOSE NATURE

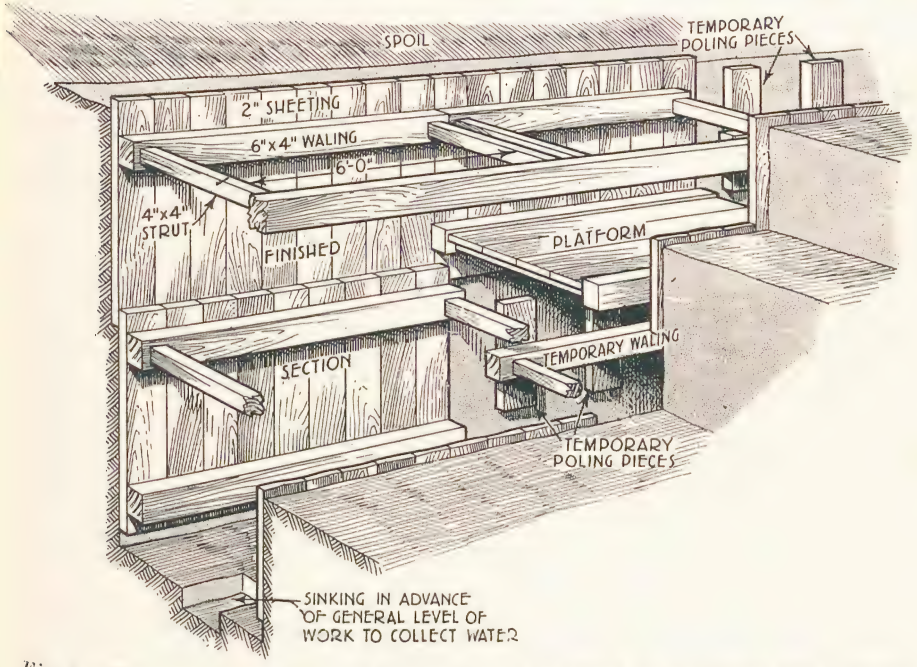


Fig. 5.—TIMBERING FOR A DEEPER TRENCH, SUCH AS MIGHT BE REQUIRED FOR A SEWER

in advance of the digging and the sloping points tend to keep the joints close. The boards being driven down in advance of the digging prevents the loose sand or waterlogged soil from " boiling up " from the bottom of the trench and thus causing voids behind the " sheeting."

Depth Governs Pressure

If the ground is very wet, and the pressure against the timbers almost approaching the laws governing liquids, then as the trench gets deeper the sizes of " walings " must be increased. The timbering for deep trenches should be calculated to meet the increase of pressure due to the greater depth.

In Fig. 7 the rectangle 6 ft. by 5 ft. shows the area supported by a " waling " 10 ft. from the surface. That part of " waling " between the struts is really a beam subjected to a uniformly distributed load due to the pressure of the earth.

How to Calculate Pressure

Assume the earth to be waterlogged and practically acting as a liquid in regard to pressure. At 10 ft. below the surface the pressure per square inch would be 4·34 lb. The pressure over the area 5 ft. by 6 ft.

$$= 5 \text{ ft.} \times 6 \text{ ft.} \times 144 \text{ (in. per sq. ft.)} \times 4{\cdot}34 \text{ lb.}$$
$$= 18749 \text{ lb.} = 167{\cdot}4 \text{ cwt.}$$

Formula for Finding Breaking Weight of Uniformly Loaded Beam

The breaking weight of a beam uniformly loaded may be found by the formula $BW = \frac{Cbd^2}{\frac{1}{2}L}$ where BW = breaking weight in cwt., C = constant (for yellow deal this constant is 4), b = breadth of beam in inches, d = depth of beam in inches, L = span of beam in feet.

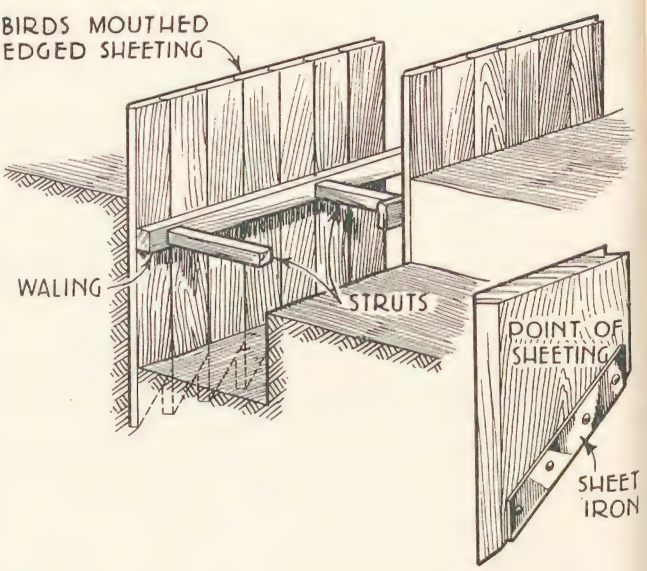


Fig. 6.—SUGGESTED METHOD OF DEALING WITH LOOSE SAND OR WATER-LOGGED SOIL, USING BIRDS MOUTHED EDGED SHEETING WITH POINTED ENDS

Fig. 6A. — SHOWING HOW THE POINTS OF THE BOARDS ARE CUT ON THE SLOPE

A beam which would break under a distributed load of 167·4 cwt. would be useless; therefore it is necessary to allow a "factor of safety." For timber a "factor of safety" of 4 is usual. So a beam capable of taking a load of 167·4 cwt. × 4 (factor of safety) is required, say 670 cwt. Try how a "waling" 6 in. by 6 in. would do.

$$BW = \frac{Cbd^2}{\frac{1}{2}L}, \quad BW = \frac{4 \times 6 \times 36}{3} = 288 \text{ cwt.}$$

This is too small. Try an 8 in. by 8 in.

$$BW = \frac{4 \times 8 \times 64}{3} = 682{\cdot}6 \text{ cwt.}$$

Therefore a waling 8 in. by 8 in. is required at 10 ft. below the surface level.

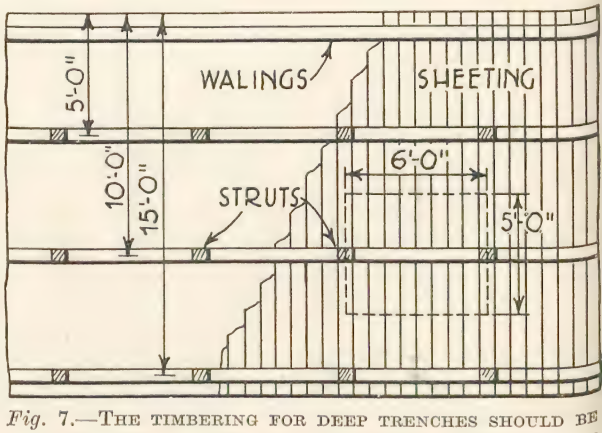


Fig. 7.—THE TIMBERING FOR DEEP TRENCHES SHOULD BE CALCULATED TO MEET THE INCREASE OF PRESSURE DUE TO THE GREATER DEPTH

The rectangle 6 ft. × 5 ft. in the above diagram shows the area supported by a waling 10 ft. from the surface.

STEEL SCAFFOLDING

NO item of builders' plant has gained popularity so rapidly as tubular scaffolding, and its many advantages over the pole scaffold leave little room for doubting that it will soon entirely replace the latter.

Correctly used, it is more rapidly erected ; less likely to deteriorate ; more convenient for internal work owing to the wide range of lengths available in the standards ; and, takes up far less valuable space when stored.

Why Great Care Is Necessary when Selecting Tubes

Although there are many varieties of fittings they all serve similar purposes and are all used in conjunction with similar steel tubing. Whatever system is adopted great care should be taken in selecting the tube, as competition has led to the introduction of cheap grades which have numerous faults. As many fittings are inserted in the ends of the tubes it is advisable that the bore should be uniform and as nearly circular as possible, and these features are not found in cheap tube.

Numbers of proprietary brands of fittings depend for their grip on the contact of a semicircular forging with the tube. If the latter is cheap, and ridged in the neighbourhood of the seam, contact takes place on a line and not on a surface, with resultant risk of slipping. Low-priced tubing, being of inferior metal, is also far weaker as a column, the position in which it has to withstand the maximum stresses.

Types of Tubing

Tubing can be purchased either painted, galvanised, or Sherardised, the galvanised probably being the best. As this adds about twopence per foot to the first cost of the tube it may be necessary to use the painted tube, but it will be equally necessary to repaint at least once a year if the scaffolds are not to look unsightly. Whilst it is too early to say that rust corrosion weakens the tube it seems likely that it will.

Painting Tubes

There are several methods of painting the tubes, and all demand a thorough cleaning-off of rust and scale, this being easily done with a wire brush driven by an electric motor through a flexible shaft. The best type of wire brush to use is one that is cup-shaped.

The painting can be done by laying the tubes in lots of a dozen,

Fig. 1.—STEEL SCAFFOLDING IS AN INDISPENSABLE ADJUNCT TO MODERN BUILDING OPERATIONS

The best methods of rapid erection of steel scaffolding is dealt with in Volume III under the heading of Operations. The present article illustrates some of the most useful types of fixings.

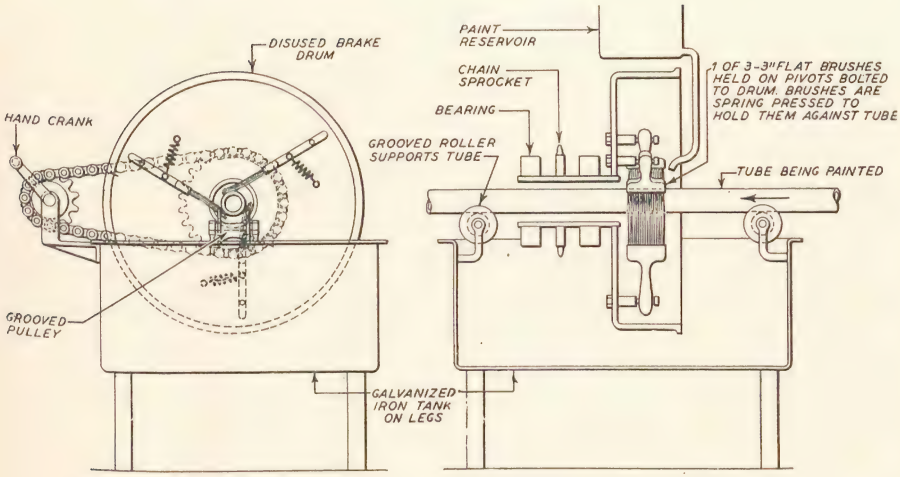


Fig. 2.—AN IMPROVISED MACHINE FOR PAINTING STEEL SCAFFOLD POLES

side by side on two horses, and flooding with a 4-in. flat brush ; by dipping in a paint reservoir made from a plugged length of 4-in. steam pipe sunk in the ground ; or by passing the tubes through a rotary head machine.

Vertical dipping needs a 17-ft. sunk pipe, an overhead block and light fall rope, and a quick-grip clamp, so that the wet tubes can be hauled out of the paint. It is wasteful and not so rapid as the machine method which is used by the largest of the scaffolding firms.

The diagram (Fig. 2) shows a machine, improvised from spare motor parts, fitted with three spring-pressed brushes fed from a drip can, the motion being obtained from a fractional horse-power motor. If power is not available a hand crank will give good results if geared to give about twenty-five revolutions of the head per minute.

Whichever method is adopted it is a surprisingly long job ; for example, the tubes from one contract at a three-thousand-seat cinema cost £53 to paint when using paint at 10*s.* 6*d.* a gallon and labour at 1*s.* 3*d.* an hour. Despite care in handling, the tubes so painted soon lost most of their covering.

How to Store Tubes

Storage space is best formed by using the tubes and fittings of the system to form cellular racks, a suitable size having four standards 10 ft. long connected by four ledgers 16 ft. long at 6 in., 3 ft. 6 in., 6 ft., and 9 ft. 6 in. from the ground ; three of these sections cross-connected in a putlog manner by 16-ft. standards will give a rack capable of holding about 40,000 ft. of tube.

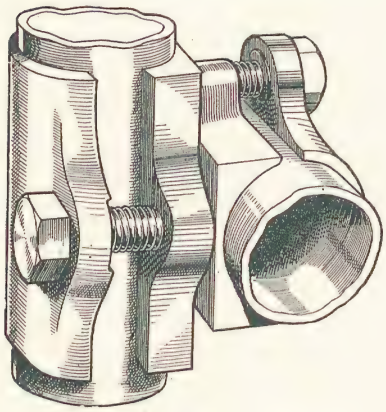


Fig. 3.—"BIG BEN" SINGLE-BOLT SWIVEL

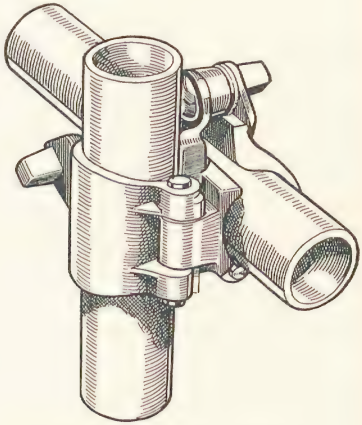


Fig. 4.—A CAMLOC FITTING
No slip up to 3·6 tons.

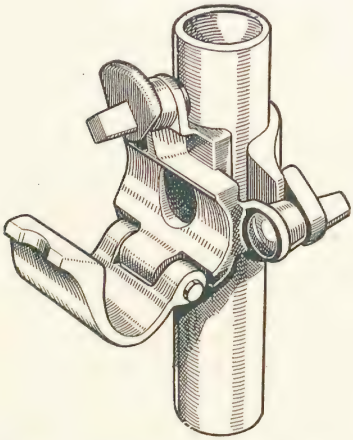


Fig. 5.—CAMLOC LEDGER COUPLING

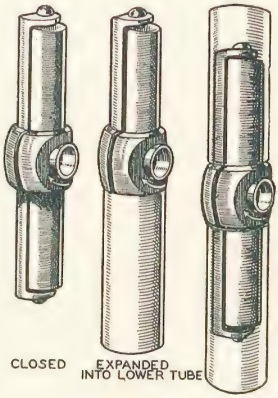


Fig. 6.—INTERNAL-EXPANDING TYPE

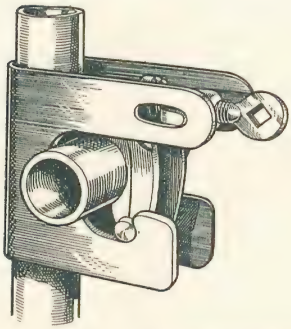


Fig. 7.—PILING LEDGER COUPLER

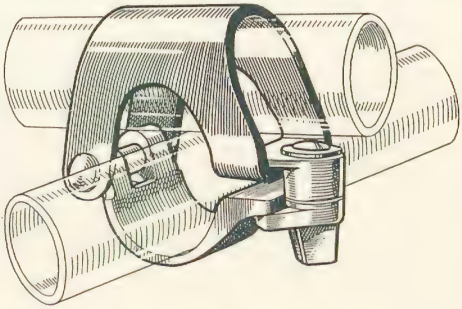


Fig. 8.—A USEFUL FITTING WITH NO SCREW THREADS AND NO LOOSE PARTS

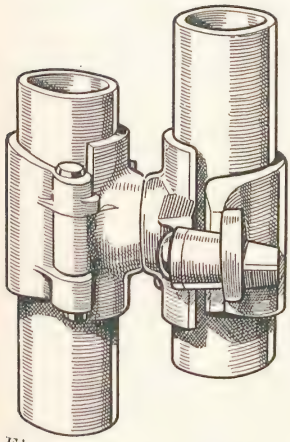


Fig. 9.—CAMLOC SWIVEL FOR DIAGONAL BRACES

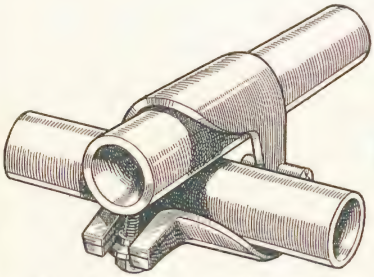


Fig. 10.—"BIG BEN" PUTLOG COUPLER

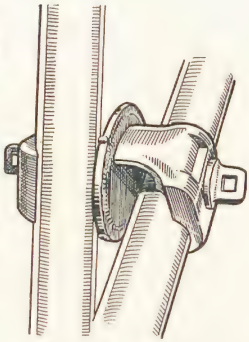


Fig. 11.—ANGLE COUPLER

For use in bracing from uprights and for handrails.

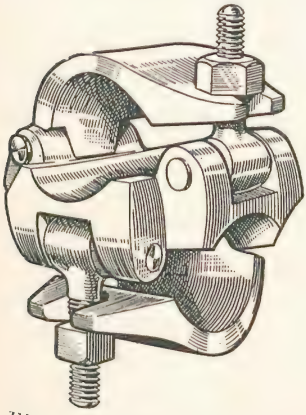


Fig. 12.—ONE-PIECE COUPLER

Useful for the ordinary cross-tie.

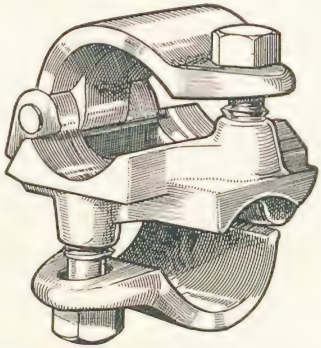


Fig. 13.—ANOTHER TYPE OF ONE-PIECE COUPLER

Fig. 14.—EXPANDING JOINT PIECE

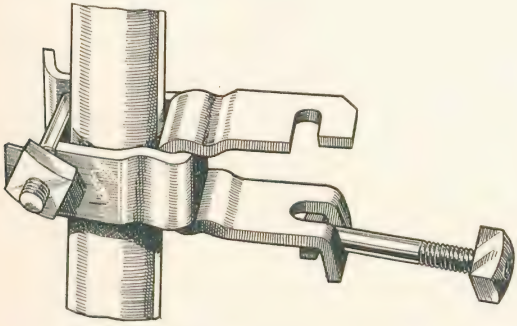


Fig. 15.—MILLS COUPLER

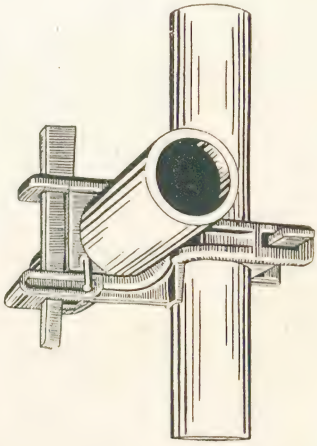


Fig. 16.—TWO-WEDGE COUPLER FOR FIXING LEDGERS TO STANDARDS

This rack should be under cover but arranged so that the lorries can be backed on to it so that the tubes can be slid in and out of the cells.

Causes of Tube Failure

Tubes fail usually from being strained out of line and so bent ; but they are too frequently used as arms for fixing gin wheels, with the same result. Attempts to straighten them are not likely to succeed unless they are put through a correctly-designed press and the best method is to cut the damaged portion out and use the short ends for reveal work. Lengths of as low as 18 in. can be used as rungs for a ladder by clamping to two parallel standards about 1 ft. apart.

The Longest Lengths Should Be Sent Out First

Where a builder's stock of tube is comparatively small, it is advisable to send the longest lengths to a job on the early loads as there is always a demand for the short lengths for interior work in the later stages of the average contract. All makers issue instructional pamphlets, and these should be given to scaffolders working with tubing for the first time, rather than to the general foreman, who is usually too busy to attend to such details. By this means a great tendency to be too liberal with braces and couplers will be avoided.

Fittings

These are made in a number of shapes to suit their several purposes, the principal ones being those that connect ledgers to standards ; those which connect putlogs to ledgers, and bracing or swivel fittings for diagonals. All are essentially clamping devices.

The ideal coupling should be strong ; have as few parts as possible ; as few loose parts as is compatible with simplicity, and lastly, require a minimum of maintenance.

Strength is assured by the use of drop-forgings. Malleable-iron castings come next in order of strength, with ordinary cast iron last. A multiplicity of parts always leads to loss of the smaller pieces, which by their size appear to be worth but little care. If the scaffolder has to carry a sack of mixed parts he will invariably lose time by blind groping in a sort of lucky dip.

Maintenance of Fittings

Maintenance can be kept to a minimum by choosing fittings which have as few threaded clamp screws as possible. In some makes it is necessary to drill and re-tap the threaded holes oversize at intervals to allow for wear, whilst the threaded portions always suffer from splashings of mortar and cement, which must be laboriously removed.

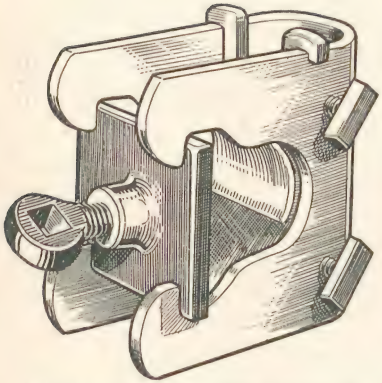


Fig. 17.—THREE-PIECE COUPLER

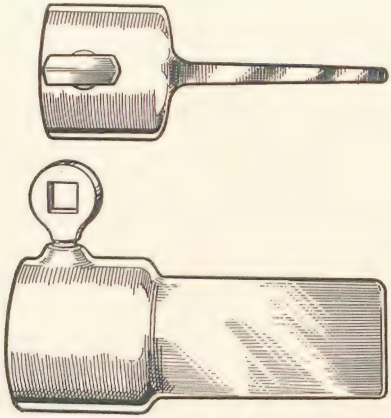


Fig. 18.—PUTLOG END FOR USE WITH ORDINARY SHORT TUBES

Fig. 19 (*below*).—TUBULAR PUTLOG

Fig. 20 (*above*).—"CHANNEL" TYPE PUTLOG

Fig. 21.—WORM SPIGOT
For joining tubes end to end.

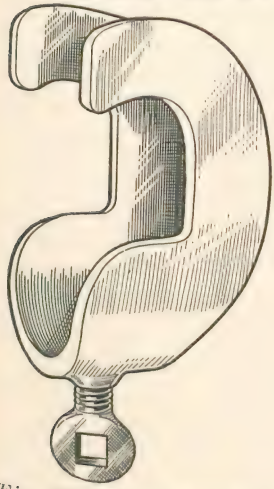


Fig. 22.—COUPLER FOR FIXING PUTLOG TO THE LEDGER

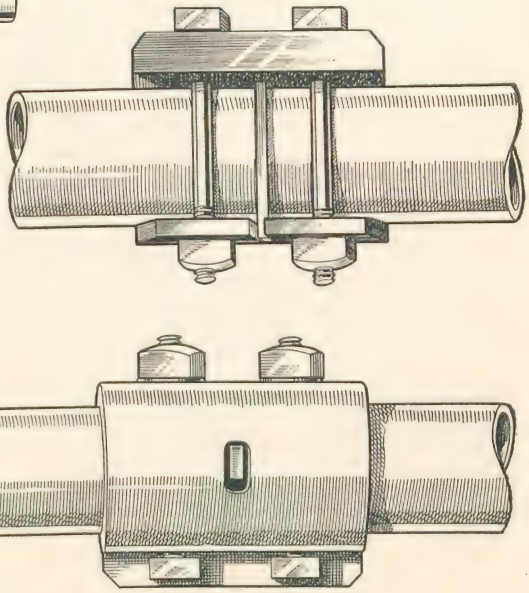


Fig. 23.—MILLS END-TO-END COUPLER

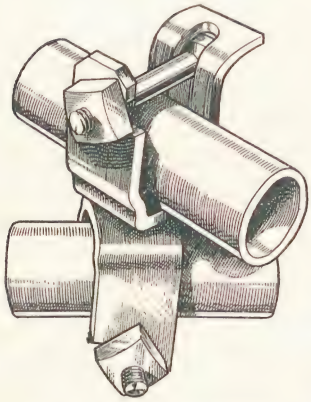


Fig. 24.—MILLS SWIVEL

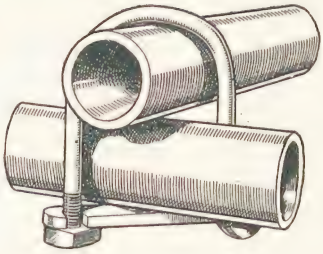
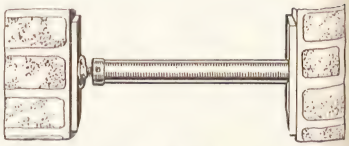


Fig. 25.—MILLS PUTLOG CLIP



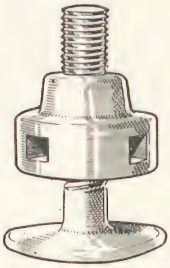


Fig. 26.—ADJUSTABLE REVEAL TIE

For tying scaffolds to buildings in occupation where ties cannot be introduced into the room.

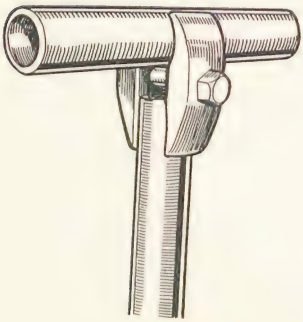


Fig. 27.—FINIAL CLIP

An excellent joint at the top members of gantries and stands.

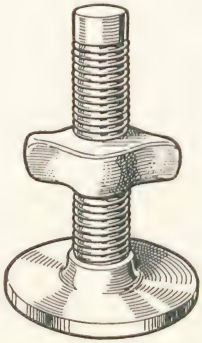


Fig. 28.—ADJUSTABLE BASE

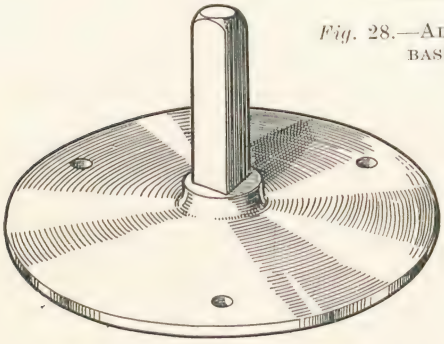
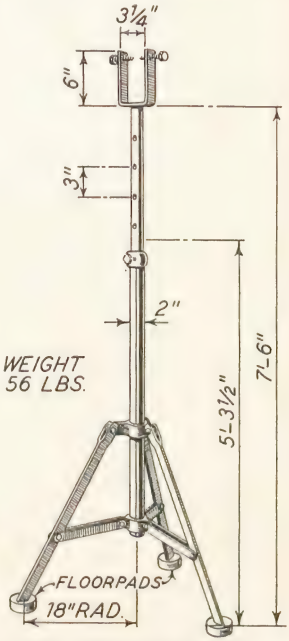


Fig. 29.—BASE-PLATE



FLOOR PADS FOR THE PROTECTION OF POLISHED FLOORS, ETC., ARE FITTED FOR A SMALL CHARGE.

Fig. 30.—PLASTERER'S ADJUSTABLE SPLIT-HEAD

These seem to be small points, but the builder cannot afford to keep men at work rectifying faults which could have and have been avoided by careful design.

One make of fitting requires no other care than dipping in waste oil in a two-compartment tank, transfer to the second compartment for draining, and final storage in bins. That this oiling tends to spoil the frictional grip of the fittings when in use is disproved by experience in oil-field work, where general greasiness of machinery and plant is common.

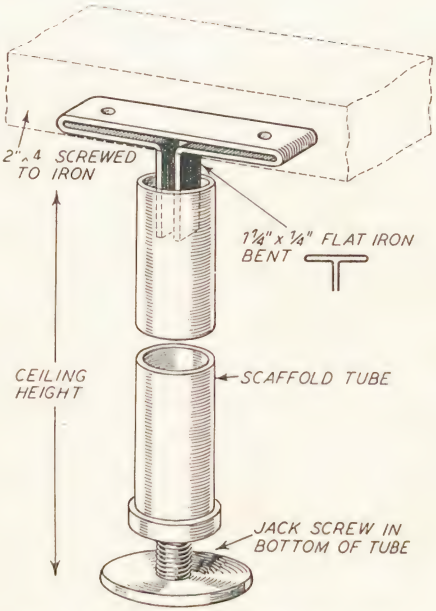


Fig. 31.—EXTEMPORISED HEAD-TREE

Load-carrying Capacities Can Be Disregarded

Salesmen often quote figures to show the load-carrying capacity of their fittings, these loads varying from 1½ to 4 tons with different makes. As these loads are far in excess of anything likely to be carried by an ordinary scaffolder even under severe conditions, and as built-out scaffolds would certainly be reinforced by suitable braces and struts, the figures may be disregarded.

Much is made of relative lightness, but the proportion of weight of fittings to tube is such that it has little bearing on transport charges and only becomes important in the erection of towers. We would refer to a fitting designed for this work which, by incorporating three fittings in one, saves a great deal of weight, but it is hardly within the usual requirements of the medium-grade builder.

Reference to the illustrations shows that some systems have fittings capable of a variety of uses, whilst other systems require different fittings for each purpose. This universality is not always achieved without sacrificing simplicity, and it is questionable whether it is an economy to employ a fitting capable of doing an important part of

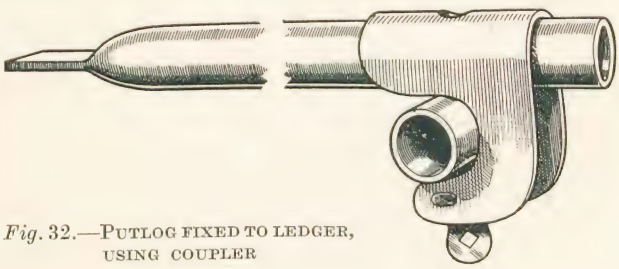


Fig. 32.—PUTLOG FIXED TO LEDGER, USING COUPLER

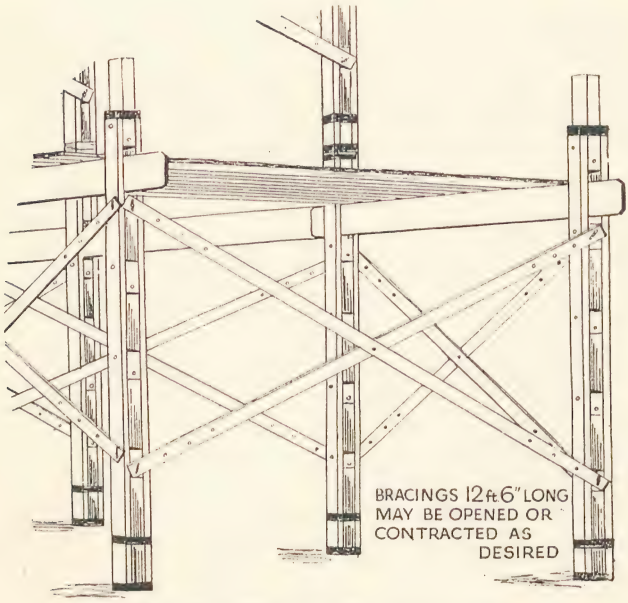


Fig. 33.—" RAP-RIG " SCAFFOLDING

the work by using it for some simpler job which could be carried out by a different and cheaper fitting. Any ledger coupling will serve as a putlog clip, but all systems have the two as separate designs.

Other Uses of Tubular Scaffolding

Tubular scaffolding can be used for several purposes. By means of small screw jacks inserted in the tubes they may be used for the support of shuttering in place of the more expensive roof shore. Pieces of flat iron bent as shown (Fig. 31), when screwed to lengths of 2-in. by 3-in. or 2-in. by 4-in. deal, form efficient head trees ; or finial clips can be purchased which will carry short tubes as horizontals.

Saving of Putlog Holes

One of the advantages of steel scaffolding is claimed to be the saving of putlog holes in the brickwork. This is true in some cases, but there are putlogs with such thick ends that they cannot be retained in the joints of the brickwork when the mortar joints are specified $\frac{1}{4}$ in.

Tying-in of the Scaffold

The tying-in of the scaffold by means of reveal screws inserted in short lengths of tube can be a dangerous process when soft facings are used, and it is preferable to use some form of internal fastening at intervals to guard against spalling of the bricks and loss of grip.

Base-plates

Except in special circumstances there does not seem to be much need to purchase the base-plates which are listed by most systems.

a 2-in. by 9-in. deal forming a satisfactory bed and allowing the tube standards to bite their way into a stable position. Where base-plates are used care must be taken that the standard is not canted when withdrawing it from the upright peg, as some of the latter, being badly butt-welded, tend to snap off at the weld.

Steel Scaffolding Used for Interior Decorating

Interior decorating of ceilings, cornices, and the like can be conveniently carried out by the use of a movable tower made from four standards with suitable cross-bracing, each standard being fitted with a castor wheel. By using two towers with a connecting bridge the writer was able to employ twelve painters working alongside one another and to complete in one night a job which formerly took three.

Some Interesting Conclusions

A recent inspection of a number of scaffolds erected in tube with different systems of fittings leads to the following conclusions as regards steel. Users are inclined to overdo standards ; too many fittings are carelessly fastened, a fault rarely seen on pole scaffolds with either chains and roses or wires ; guard boards, except in the case of the largest contractors, were conspicuous by their absence, despite the fact that bent iron clips to hold them in position are the cheapest of the fittings ; guard rails were in some cases entirely absent.

There is no need to waste time over commiserating with the uneconomic use of tube, but there are no words strong enough to condemn a builder who with the fullest knowledge of the dangers involved exposes his workers to risk of injury, nor is it possible to forget that the whole of the scaffolds in question were in prominent positions and readily seen by Home Office inspectors.

In purchasing steel scaffolding buy the best it is possible to afford, and if the cost of erection on its first job be carefully checked and compared with the cost of using poles it will be seen to be a worth-while investment.

Scaffolding for Interiors

A form of scaffolding in which the vertical members are built of light quarterings, separated at intervals by blocks with bolts passing through the whole, is illustrated, because it is more rapidly erected than any other system and, being of timber, is more suited to use in the interior of buildings such as churches, museums, shops, and theatres, where accidental dropping of a steel tube might cause irreparable damage.

The only loose fitting is a butterfly nut which serves to clamp flat diagonal timber braces to the standards. Scaffold boards set on edge

serve as ledgers, and where extra strength is needed special standards can be obtained which allow of the use of two scaffold boards side by side.

The cost of the system is lower than any of the steel-tube ones by about 40 per cent., and the weight is about 50 per cent. less when the correct proportion of fittings in steel systems is allowed for.

If painted, a life of ten years is to be reasonably expected, but it obviously takes up more room in storage than tube and cannot be expected to have the strength of the latter. With these limitations it can be said to fill a useful gap between poles and tube.

Full details regarding the method of erecting steel scaffolding will be found in Volume III.

QUESTIONS AND ANSWERS

What is the best method of storing Steel Scaffolding Tubes ?

By using the tubes and fittings of the system to form cellular racks, a suitable size having four standards 10 ft. long, connected by four ledgers 16 ft. long, at 6 in., 3 ft. 6in., 6 ft., and 9 ft. 6 in. from the ground. Three of these sections cross-connected in a putlog manner by 16-ft. standards will give a rack capable of holding about 40,000 ft. of tube.

What are the principal fittings used in Steel Scaffolding Work ?

(1) Those that connect ledgers to standards.
(2) Those that connect putlogs to ledgers.
(3) Bracing or swivel fittings.

What are the essential features of the ideal Coupling ?

It should have as few parts as possible ; as few loose parts as is compatible with simplicity ; and should require a minimum of maintenance.

What is the most likely cause of Tube Failure ?

Tubes fail usually from being strained out of line and so bent. Using tubes as arms for fixing gin wheels may also cause the same result.

What is the best method to adopt for the tying-in of the Scaffold ?

It is best to use some form of internal fastening at intervals, to guard against spalling of the bricks and loss of grip.

PRECAST CONCRETE STEPS

THE accompanying builders' data sheet shows the methods adopted for the construction of various types of concrete steps erected *in situ*.

The design of moulds shown in this article is for the more artistic type of precast steps which are so extensively used in public buildings, hotels, etc.

Such moulds are rather expensive to make, but of course many castings can be made from each mould. Therefore, if the cost of the mould is spread over the quantity of castings produced, it will be found that the cost of mould per casting is a very low figure.

Designing the Steps

The mould for the first tread is so arranged as to make both ends circular. Of course, if the run of steps is to be carried on one side by a party wall, only one end would be circular. Likewise, the remaining treads would show the return nosing only at one end. Should the steps be open on either side when erected, they would obviously be made with the returns at either end.

Making the Moulds

It is essential for the moulds to be made perfect for this class of work, since the castings produced invariably are required to be polished and finished off to show perfect details. It is obvious that if the moulds are

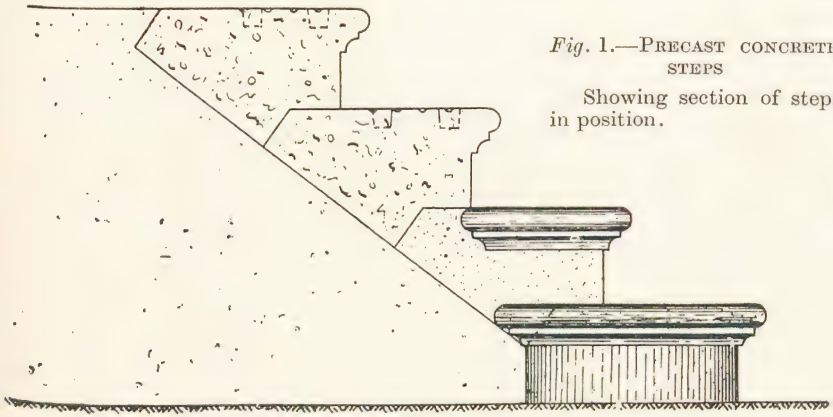


Fig. 1.—PRECAST CONCRETE STEPS

Showing section of steps in position.

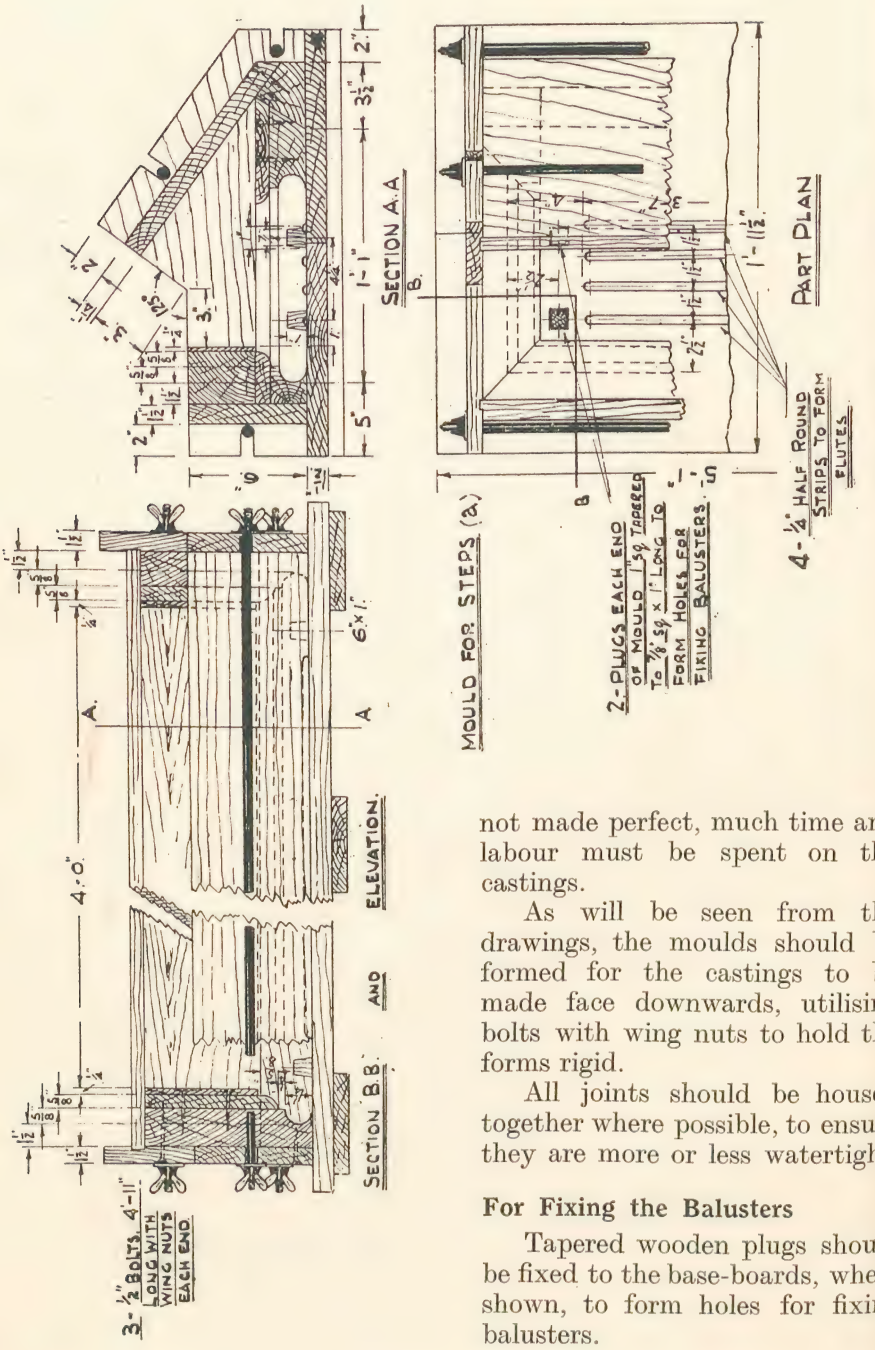


Fig. 2.—MOULD FOR STEPS

not made perfect, much time and labour must be spent on the castings.

As will be seen from the drawings, the moulds should be formed for the castings to be made face downwards, utilising bolts with wing nuts to hold the forms rigid.

All joints should be housed together where possible, to ensure they are more or less watertight.

For Fixing the Balusters

Tapered wooden plugs should be fixed to the base-boards, where shown, to form holes for fixing balusters.

Hardwood or iron $\frac{1}{4}$-in. half-round strips should also be securely fixed to the base-boards to form flutes in the top of the treads.

Moulded Nosings

As will be seen from the drawings, the moulded nosings can be so formed by working separate thicknesses of wood finally screwed together as one block. Of course, wherever possible they can be worked in the solid.

The moulds must be made absolutely free from twist; therefore the base-boards should be very carefully made.

Timber

Selected red deal is suitable for the greater portions of these moulds—shakes, of course, being avoided. The plugs and half-round strips should be in hardwood or iron.

Dismantling Moulds

To dismantle, the moulds must be turned upside down. The base-board should be gently tapped before withdrawing. This method will more or less free the plugs and strips. The side forms should be evenly and carefully withdrawn to ensure against broken arrises.

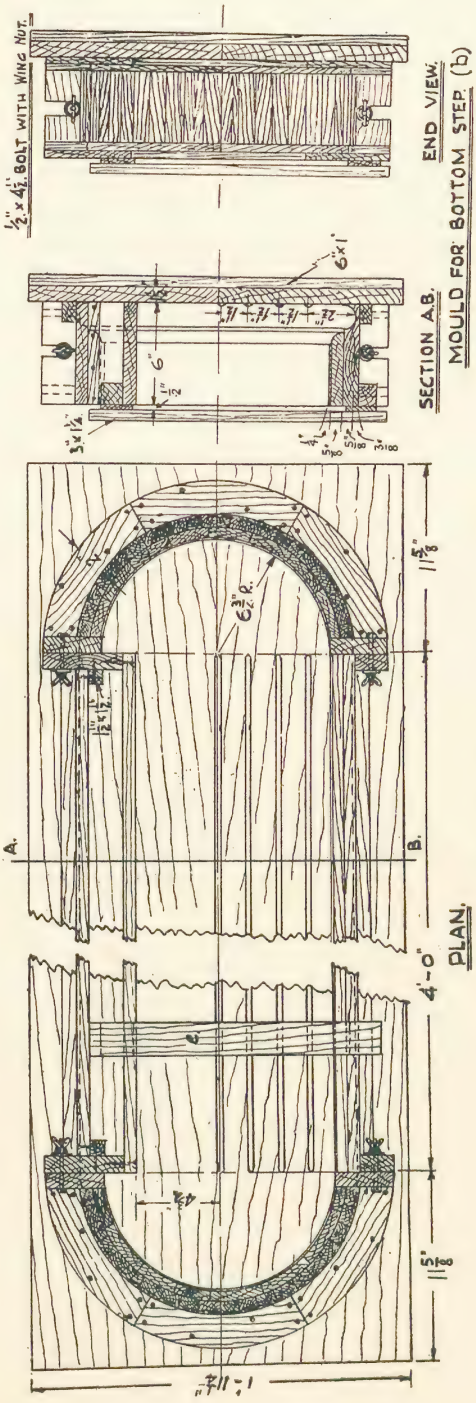


Fig. 3.—Mould for bottom step

Treatment of Moulds

All moulds should be treated before casting to prevent the concrete adhering to the forms. For this particular job, it is as well to shellac the finer members, if not all the mould. Follow this with an even coat of paraffin and raw linseed oil.

Mix of Concrete

The aggregates for such work will depend upon the type of finish required. If polished work is to be the finish, then marble, speckled granite, or other suitable stone for polishing must be used, but for unpolished work, grey granite should be used.

The proportions should be $2\frac{1}{2}$ parts $\frac{3}{8}$-in. to $\frac{1}{8}$-in. marble or granite, $1\frac{1}{4}$ parts $\frac{1}{8}$-in. to dust, and 1 part cement, either coloured or ordinary.

The mixing of these aggregates and cement must be carefully carried out, care being taken not to use the water too freely as a stiff, plastic mix is required.

Placing the Concrete

The concrete should be carefully placed and thoroughly consolidated, especially on the bottom and sides of the mould. Some steps are required to show a carborundum face, and to obtain this either the carborundum can be sprinkled over the bottom of the mould in its dry state before the filling commences, or it can be mixed with the first small batch of concrete.

Curing

The castings should remain in the moulds four days from the time of being filled, and when taken from the moulds they should be kept damp and covered for a further seven days before polishing, if that is to be the finish.

Finishing Castings

When the castings are sufficiently hard, say, seven days from the dismantling, they can be lightly rubbed with a carborundum stone and finally finished with a snake stone, utilising plenty of water during the rubbing process. This will give a fairly good polished surface. Of course, there are several types of machines on the market for this class of work.

Reinforcement

It is not necessary to reinforce steps as shown in this article as far as strength is concerned. But such products are subject to being bumped about in transit, therefore it is better to be on the safe side. Three $\frac{1}{2}$-in.-diameter mild-steel bars hooked at either end, spaced at equal distances and central, will ensure against transit breakages.

FURTHER NOTES ON MODERN FLOOR COVERINGS

PERMANENT FLOORS

IN a previous section reference has been made to semi-permanent floors, i.e. rubber, wood blocks, cork, linoleum, etc. We now deal with floors which when laid are done so in a manner that should render their life equal to that of the building itself. Under this heading may be mentioned stone, tile, marble, mosaic, and terrazzo, and possibly the various types of magnesite composition floors and granolithic floors.

Magnesite Flooring

This may be considered as one of the permanent types of flooring, being a monolithic mixture laid on the concrete and spread in the manner of cement screeding. It is a compound of magnesite, magnesium oxychloride, and different fillers ranging from sawdust to powdered asbestos. Magnesium chloride being very hydroscopic, this type of floor is unsuitable for damp situations, where it is liable to sweat and eventually break up and lift from the concrete base.

Preparation of Ground Concrete

On ground concrete, therefore, a damp-proof bitumen coating should first be spread over the floor, and a further precaution consists of diminishing the proportion of sawdust and substituting an inorganic filler. This may render the floor harder, but will assist it to remain satisfactory in humid surroundings.

Laying Magnesite Flooring

Under normal conditions, magnesite flooring is laid directly on the concrete without a cement screed, in one or two layers (preferably the latter for first-class work), and will set hard in about forty-eight hours.

Ordinary Floors

For ordinary floors the compound should be composed of about 45 per cent. ground magnesite and 55 per cent. wood flour, asbestos, or talc, and chloride of magnesium.

Heavy-duty Floors

Heavy-duty floors can have a slightly different mixture—of about 55 per cent. ground magnesite and 45 per cent. graded hardwood sawdust and chloride of magnesium.

This can be laid in one coat on solid flooring $\frac{1}{2}$ in. to $\frac{3}{4}$ in. thick, but ordinary flooring is best laid in two coats $\frac{3}{8}$ in. thick, the lower layer being composed of 25 per cent. ground magnesite and 75 per cent. sawdust. The bottom layer should be reinforced with wire mesh or light expanded metal to prevent cracking. If the whole floor is not reinforced in this way, on account of expense, strips about 2 ft. wide should be laid over all joists and beams embedded in the concrete, or temperature changes in the steelwork may tend to crack the magnesite flooring above.

Magnesite Flooring Must Not Come in Contact with Ironwork

All ironwork in contact with magnesite flooring should be treated with red lead to prevent corrosion, and where pipes come through floors a sleeve piece should be fitted so that the pipe can be removed without disturbing the floor.

Non-slip Surface

To ensure a non-slip surface, Alundum compound can be worked into the top layer in the proportion of $2\frac{1}{2}$ lb. of Alundum to 1 sq. yd. of finished flooring, the granules being incorporated as the floor is laid to a depth of about $\frac{1}{4}$ in. Magnesite flooring should not be allowed to touch plaster, which may absorb the magnesium chloride and after a time break up and powder away. It is best to divide the two materials by a definite break between walls and floor, which can be done either with a suitable metal strip, a wood skirting, or a Portland cement cove.

These jointless floors are waterproof, dustless, and hygienic and, as they are laid without a cement screed, save cost.

Cleaning Floors

A few special precautions must be taken in cleaning them. Soap or soda should never be used, but if the surface becomes very dirty it should be well scoured over with steel wool or a bunch of steel shavings. When the dirt has been removed the whole surface should be given a rub over with a good linoleum polish diluted with turpentine. Periodical dressings of raw linseed-oil feed the floor and preserve the brightness of the colours.

Dermas Flooring

Another floor composed largely of the same fillers and magnesium chloride, has in addition an asphalt emulsion which eliminates the need of feeding the composition with oil from time to time. It also makes a very resilient surface to walk upon.

Terrazzo Floor

Before laying this type of flooring, which is in fact a rough imitation of mosaic, the surface of the sub-floor must be carefully cleaned, soft patches hacked off, and a screed of cement mortar applied. It has

been found by experiments at the Building Research Station that the application of a slurry to the sub-floor, under the screed, improves the bond. The slurry is composed of neat cement and sand (1 to 1) and is followed immediately by the screeding, composed of 2½ to 3 parts of clean sand to 1 of Portland cement.

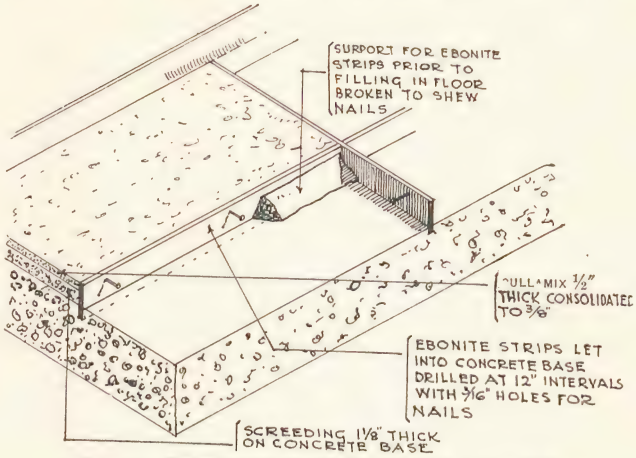


Fig. 1.—Preparation of Floor for Cullamix

When the screed is dry it should be cleaned of dust and wetted to a moderate extent, enough to prevent too great a suction when the terrazzo is laid.

Laying

Terrazzo is a compound of crushed marble, aggregate, and cement. Owing to the fact that it is made with a mixture rich in cement, and not well graded according to the ordinary mixing formula, there is often a tendency to crack and shrink after drying. To counteract this tendency terrazzo should be divided into panels with brass or ebonite strips set in the screed. These panels can be arranged to form any desired pattern in the floor but none should have greater superficial area than 20 ft. Even so, the corners tend sometimes to warp and lift; therefore, when laying, special care should be given to the work in these places.

Different Aggregates

Other aggregates that can be employed are crushed coloured enamels and glass mixed with coloured cements, and the natural colours of the marbles can be still further enhanced by employing white cement in which to set them.

Colours for Terrazzo Floors

There is a wide range of colours in terrazzo and all are satisfactory except blue and green. Blue will move in the cement where coloured cement is used, and seep to the surface, while all but the best qualities of green are liable to fade. Black is another difficult tone. The aggregate comes from Belgium and is sold in four different qualities. Second-best is usual for good black flooring, and third-best may be used for

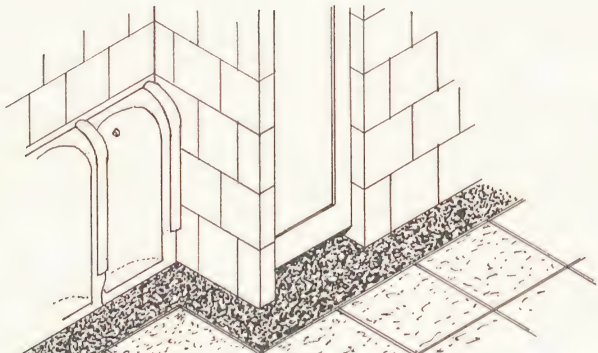


Fig. 2.—CULLAMIX FLOORING WITH BLACK BORDER AND LIGHT-COLOURED PANELS DIVIDED BY EBONITE STRIPS

cheaper work. This cheaper type of aggregate has fine white markings, and the resulting floor will be of a grey-black shade. Black terrazzo takes some months to mature and will not have its proper lustre until the salts have worked out. These will form a whitish film on the surface at first, but after six months or so should cease to effloresce, and the floor will become a dead, permanent black.

Setting

Terrazzo should be allowed to set slowly and should be kept moist until hardened, though when laid *in situ* these ideal conditions cannot be complied with, one of the most serious dangers being the testing of the hot-water system (if one exists) before the floor is dry. The uneven setting caused by the heat and draughts may set up strains in the hardening cement which will lead to bad cracking of the floor.

Precast Terrazzo Panels

Precast terrazzo panels about 12 in. square, made in a hydraulic press, will solve this difficulty where speed is important. These tiles are kept in water for several days after manufacture and thus develop the full strength of the cement ; they can then be laid at once and after about twenty-four hours are fit for traffic.

The final process in laying the floor is to clean off and polish by rubbing with a weighted stone and water until a perfectly smooth surface is obtained. Terrazzo when laid is usually given a grit finish, but even so the surface in time may become slippery through several causes, one being the coating of the surface from wax-polished floors, the grease of which is carried on the feet from rooms in an office building to the terrazzo passages. The old method when this occurred was to rub down again with rubbing machines, but modern methods include the use of a solvent which can be employed without skilled workmen.

Cleaning

Soap, of either bar or powdered varieties, should never be used in cleaning a terrazzo floor. Clean, plain water mopped on will remove all dirt, which cannot be ground into the hard surface and will come away readily with elbow-grease.

The Use of Carborundum to Prevent Slipping

Carborundum can be used to prevent slipping on wet terrazzo round swimming-baths or on permanently wet floors, but as the material which is dusted into the aggregate as it is laid acts by sticking slightly up above the general floor surface, it is not very satisfactory for people who are not wearing shoes.

Indented tiles of terrazzo are now made in which the surface is covered with V-shaped grooves that act by suction on the soles of the bathers' feet. These tiles are very hard and will stand up to wear better than ordinary terrazzo laid in the usual way.

Cullamix Floors and Tiles

This is a terrazzo type of material composed of coloured cement and special aggregate ready mixed for use, the chief characteristic of which is an exposed white aggregate of chips embedded in a matrix of coloured cement, the shade and colour being obtained through the tone of the matrix. This is the reverse of ordinary terrazzo, where the colour is produced by the coloured particles of the aggregate.

Range of Colours

The range of colours in cements used in Cullamix is large, ranging through pink, terra-cotta, brown, violet, black, green, burnt sienna, and yellow to white. Large areas are divided up into separate colours by means of ebonite or brass or bronze strips in the same manner as terrazzo floors.

Preparation of Floor

Before laying Cullamix the concrete floor should be well brushed clean and have a surface sufficiently rough to give a good key. The dividing ebonite or brass strips, $1\frac{1}{2}$ in. deep and $\frac{1}{8}$ in. thick, should be fixed on the concrete about 10 ft. apart, and the strips then drilled with $\frac{3}{16}$-in. holes about $\frac{3}{4}$ in. from the top at 12-in. intervals to allow of 1 in. wire nails being passed through them. The strips are first held in position and dabs of cement mortar pressed against the free side to within $\frac{5}{8}$ in. of the top of the strip. The nails are then inserted from the other side so as to project evenly both sides of the strip, and the mortar is then built up on the other side. The strips should then be left for the mortar to harden sufficiently to hold them firmly in position.

Fig. 3.—LAYING A GRANOLITHIC FLOOR (1)

Laying the topping on the base layer. After throwing the granolithic with a spade it is roughly smoothed with a float. Notice the straight-edge supported on the dividing face-boards.

Fig. 4.—LAYING A GRANOLITHIC FLOOR (2)

The straight-edge is pulled towards the workman with a slight tamping action, to produce the level granolithic surface.

Fig. 5.—LAYING A GRANOLITHIC FLOOR (3)

Filling in the joints in the finished floor after removing the facing-boards between the bays. The straight-edge can be seen on the right.

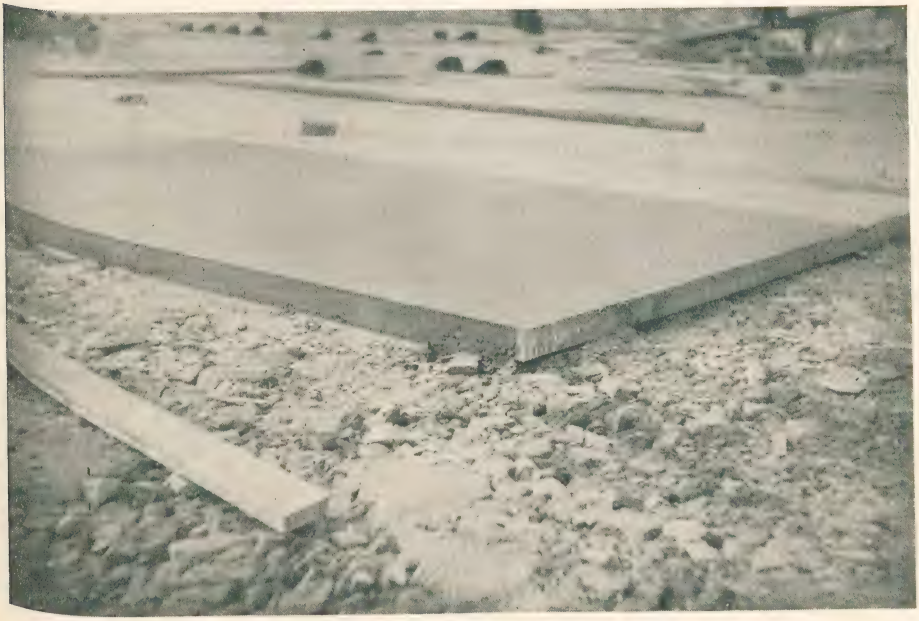


Fig. 6.—LAYING A GRANOLITHIC FLOOR (4)

Portion of the finished floor, the facing-board removed at external edge, showing the hard-core bottom of broken brick, and the lower and upper layers of granolithic.

The Screed

The concrete sub-floor should be thoroughly wetted with clean water, and unless it is in a new building a thin slurry of neat cement brushed on to give a key to the screed. The screed and topping of Cullamix is approximately 1½ in. thick, the screed accounting for 1⅛ in. of this depth, and the topping for ½ in. nominal thickness, but this will be reduced to ⅜ in. when tamped down and consolidated into the screed. The mix for the screeding should be 4 parts aggregate of clean washed shingle graded from ⅜ in. down, 2 parts clean sand, and 1 part Portland cement.

The Cullamix in plastic form is laid on this to the required level while the screed is still green, and levelled up by a wood straight-edge, not scraped off but tamped down. A final smoothing is then made with a steel trowel. Just before setting, it should be rolled with a steel roller until the surface cement begins to stick, when this should be removed with a steel trowel with a scraping action.

When dry, the whole surface of the floor is brushed with a wire brush.

Floor Polishing

If the floor is to be dry polished it should be kept damp for two days after laying before being allowed to dry naturally, but if wet polishing is required the floor must be kept damp until this is done.

Wet Polishing

Wet polishing produces a smoother surface and should be done about a week after laying ; the actual time will vary with the temperature and the colour employed in laying the floor. The surface is first rubbed down with carborundum stone until the white aggregate is everywhere exposed, when the rubbing should cease and the floor be washed. If small pittings show after rubbing down, these holes should be filled in with grout mixed to a plastic consistency and worked in with a wooden float. A light sprinkling of cement should then be applied and the floor rubbed over with a soft rag, After a further lapse of 24 hours the final rubbing may be carried out.

Cleaning Cullamix Floors

Acids should never be used in cleaning Cullamix floors, and an effective means of preventing staining by oil is to treat the surface with paraffin wax dissolved in petrol and applied with a rag.

Cullamix Tiles

Cullamix can also be laid in the form of tiles. Each tile is made under pressure and is true to shape, and provided with a keyed back ready for laying. Before being sent out they are polished with wax and when laid can be kept in good condition by an occasional application of wax polish.

The tiles are made in 6-in. by 9-in. squares, and are fireproof, non-crazing, fadeless, and lighter in weight than quarry tiles. They can also be cut in the same way as glazed tiles.

Cullamix floors are suitable for hard wear in such places as industrial buildings, canteens, and factories and power houses on account of the freedom from dust.

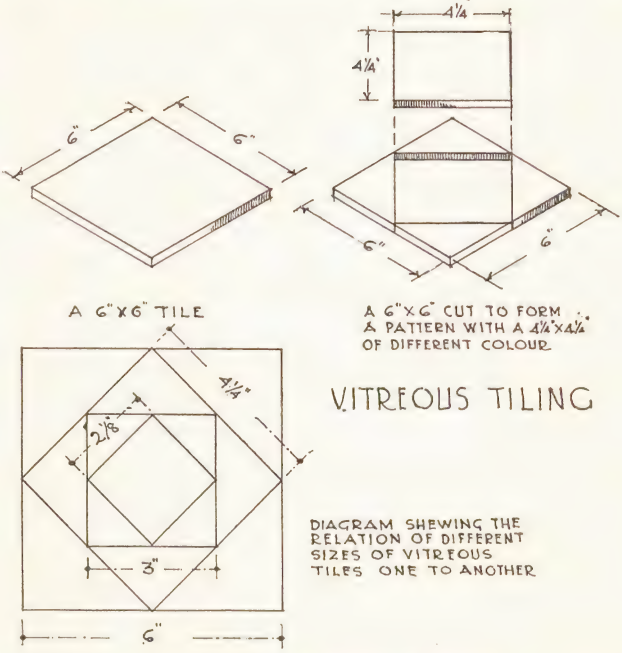


Fig. 7.—SIZES OF VITREOUS TILING

Asphalt

This material, which is a form of natural bitumen, is either laid as a powder compressed by rubbing with a hot iron or, more usually in building work, heated in cauldrons and applied hot as a mastic.

The best-known source of the former is the Pitch Lake in the island of Trinidad, and of the latter the Val de Travers in Switzerland, which supplies what is really a bituminous limestone.

A plain asphalt floor from $\frac{1}{2}$ in. to $1\frac{1}{4}$ in. in thickness need not, in many cases, be covered with any other material. If it is carried up the walls and finished with a coved skirting, such a floor will take a good polish and makes a pleasing blackish base for coloured rugs. But in laying the material the concrete floor must have an absolutely dry surface to get proper adhesion, and fine ashes are sometimes brushed over the surface immediately before laying.

Colorphalte

Colorphalte is a rock asphalt fluxed with Trinidad Lake asphalt, and has colouring pigments added. It can be laid as ordinary asphalt, already described, in a mastic state ; or in tiles already hardened and coloured. Where dustless floors are essential, or where salt or sea water is present, asphalt forms an excellent flooring material ; and in chemical works and laboratories, where corrosive acids are likely to be spilt, the best type of floor is one laid with acid-resisting asphalt.

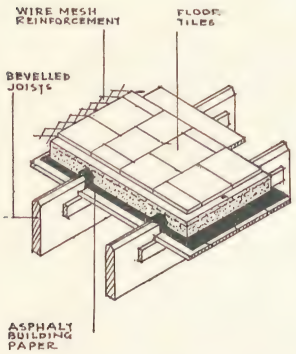


Fig. 8.—TILE AND CONCRETE FLOOR LAID ON BOARDING AND ASPHALT PAPER

Note that the concrete is reinforced with wire mesh and the top edge of the joists bevelled. The underboards are supported on fillets.

Mosaic Floors

These floors are made of tesseræ or small cubes of sanded glass, burnt clay, or marble. In the best work it is usually set piece by piece in the prepared cement bed, but a cheaper commercial method is to fix the cubes face downward on paper with an adhesive. The patterns thus made up at the works are transferred to the cement grout on the job, and when dry the paper is washed off. A final operation is to run liquid cement into the spaces between the cubes.

Marble cubes wear the best as a mosaic floor; burnt clay has a tendency to become slippery in time and should have a non-slip material mixed with it. Glass mosaic has a rougher surface owing to silica in the composition, but sometimes has a tendency to "dust up" under heavy wear. Vitreous mosaic is more suitable for flooring than glass.

Cement Mix for Mosaic Floors

The mix of the cement used is important, and one of the best is composed of Leighton Buzzard sand and "Snowcrete." The finished thickness of a mosaic varies, but is never more than $\frac{3}{4}$ in. above the concrete —including the cement and sand bed on which it is laid.

Marble and Stone Paving

To lay these floors, the screeding under the slabs must be carefully levelled as the slabs are liable to crack if unevenly bedded. Marble flooring is often bedded in a mixture of stone dust and lime known as Parian cement, but the majority of marbles are not suitable for heavy wear, and cannot be obtained in large slabs. Failure of floors is sometimes caused through choosing marbles of different wearing capacities and laying them together when making up the design, and it should be remembered that green and black tones are usually harder than white. The same danger is present when a mixed stone and marble floor is laid, and the abrasive properties of the various materials should always be ascertained in such circumstances.

Laying a Marble Floor

In laying a marble floor, about $\frac{1}{2}$ in. of screeding is first laid over the whole of the concrete, made up of sand and Portland cement. The screed should be finished below the floor level a distance equal to the thickness of the tile plus $\frac{3}{4}$ in.; that is to say, if the marble is $\frac{3}{4}$ in. thick, the screeded floor should be $1\frac{1}{4}$ in. below the finished floor level. The composition

cement for laying marble should be very dry and made up in a proportion of 8 to 1 ; at least three days should be allowed for the floor slabs to set, and no heavy traffic should be permitted before the end of fourteen days at the earliest.

Washing powders often contain caustic alkali and should never be used on marble floors ; a similar prohibition must also be exercised over all powders containing fats, as these will render the floor slippery when dry. Marble is always a dangerous floor, and should never be polished to a higher degree than a grit finish if it is to take any considerable amount of traffic.

A Simple Method of Making a Surface Non-slippery

The Building Research Station has suggested a simple method of making safe a surface which has worn slippery. They suggest a compound of sawdust and hydrochloric acid in the proportion of 16 oz. of commercial acid to 1 gallon of water. This is mixed with sawdust until it forms a sloppy paste, which is then spread over the marble to a thickness of about 1 in. and left for fifteen minutes. On removal the floor is washed two or three times with clean water, when the surface should be safe to walk upon, and no discoloration of the marbles will have occurred.

Marbles Used in Flooring

The following are some of the most common marbles used in flooring :

Piastraccia

A white, veined marble, the white ground being a pure white. It is suitable for the treads and risers of stairs not subject to heavy wear.

Sicilian (Carrara)

A hard marble with a bluish-white ground and light grey veins. The name Sicilian is an English misnomer, as the marble is not quarried in that island but at the Carrara quarries. It is used for floors and stairs and on any floor subject to hard wear.

Roman Travertine

This differs from the usual marbles, having been subjected to no heat or pressure in geological ages, but being formed by slow deposits from lime-bearing water, in a similar manner to stalagmites. It is very hard-wearing and stands exposure to the weather well.

Zola Reppen

Of similar geological formation to Travertine and of a grey tone. It wears well and for many years has been used in Vienna for steps and landings.

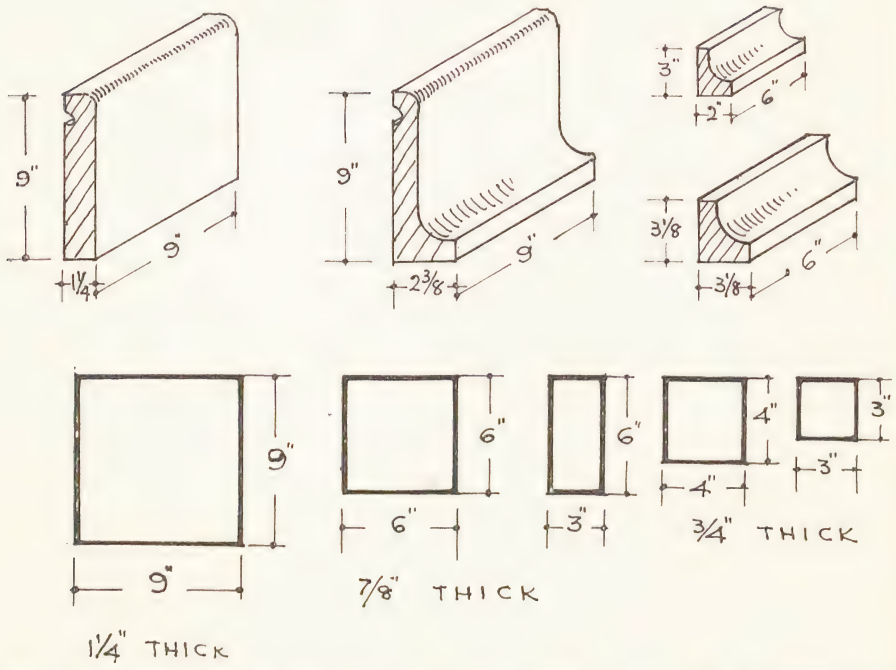


Fig. 9.—GENERAL SIZES OF TERRA-COTTA AND QUARRY TILING, WITH SKIRTING AND COVING TILES

Siena Fleuri

A real marble of yellowish-orange shade. A handsome marble for interior paving where richness without hard-wearing qualities is required.

Swedish Green

This marble comes from the quarries at Kolmården. It is geologically a cross between lime marble and serpentine, but nevertheless can stand up to hard wear and is suitable for pavements and external work. There are two varieties, known as G3 and NYT2, the latter being somewhat darker in tone but obtainable only in 18-in.-thick beds.

Tinos

A dark green serpentine suitable for pavements and of close texture, which stands up to weather well and can be had in large blocks.

Ashburton

A dark blackish-grey marble with greenish fossil spots, quarried in Devonshire. Fossil marbles are often unsound in use, but Ashburton is a good-wearing marble under normal conditions and is much used for church steps and paving in the county of its origin.

Tiles

Usual tiles employed in flooring may be classified into Terra-cotta, Quarry, Tesselated, and Vitreous.

Terra-cotta

Terra-cotta tiles are made from clays, found in various parts of England, which contain a large percentage of silica. The red colour common to terra-cotta paving is usually caused by the presence of oxide of iron. The tiles can be obtained in a variety of sizes and are best laid with the specially made skirting or coved angles supplied by the makers. Such flooring is smooth, clean, and strong enough to stand up to ordinary wear and tear. Various sizes of terra-cotta tiles are manufactured in different thicknesses, and it is well to select sizes having the same depth, to simplify the level of the screeding below.

Quarry Tiles

Quarry tiles are usually of a large size : 9 in. by 9 in. or 12 in. by 12 in., though smaller sizes are obtainable. They are composed of a coarse clay which, when broken, shows in section a fine skin over a rougher interior. They are suitable for ordinary wear and general domestic use in sculleries, wash-houses, etc., but will not stand up to heavy traffic, having a tendency to powder and disintegrate when the skin is broken through.

Tesselated and Vitreous Tiles

Tesselated and vitreous tiles are similar in general appearance, but the latter are fired at a higher temperature and are composed of a slightly different clay containing a higher percentage of felspar ; they are therefore harder. Both these types of tile are made under pressure and are burnt well, so that when broken they show the same consistency throughout the tile.

Sizes of Vitreous Tiling

The usual size for vitreous tiling is 3 in. by 3 in. and smaller. These dimensions ensure the tile not twisting when fired, but sizes of $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. are possible, or even larger, though owing to the rejections from the kilns of these larger sizes the cost rises sharply. The common sizes for tesselated tiling are 6 in. by 6 in. and divisions of this size. The most usual are 6 in. by 6 in., $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. (this being exactly half the area of 6 in. by 6 in.), 3 in. by 3 in., and smaller. The common thickness is $\frac{1}{2}$ in., but $\frac{5}{8}$ in. is made in certain colours.

Laying the Floor

To lay the floor, it is first screeded to $\frac{5}{8}$-in. thickness ; the tiles are then set in $\frac{1}{4}$ in. of cement and sand and well beaten into the material. Joints

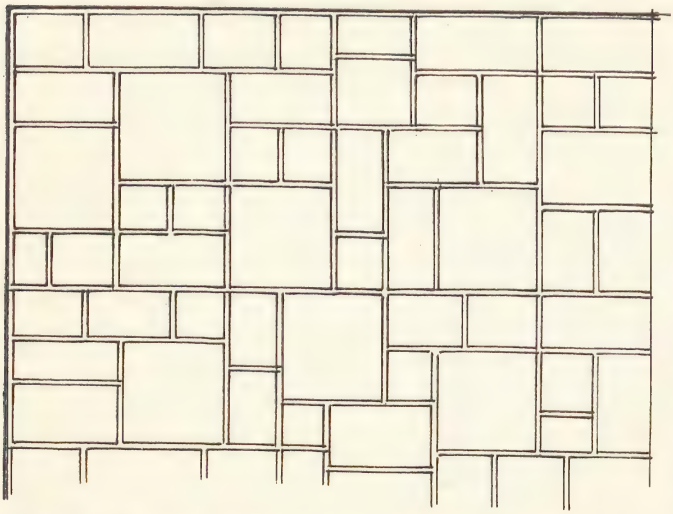


Fig. 10.—RANDOM QUARRY-TILE FLOORING, USING 9 IN. BY 9 IN. AS THE LARGEST UNIT

are grouted in with cement and sand and the surface cleaned off. Over large areas a bituminous surround is sometimes put to obviate cracking should movement take place in the building. Acid-resisting floors and floors of dairies, where there is danger from lactic acid, are frequently laid with vitreous tiling having the joints filled in with super cement or bitumen ; in the latter case great care must be taken to prevent staining the tile surface.

The colours of tesselated and vitreous tiling are fast, but brilliant tints are impossible and designs incorporating bright greens or reds cannot be carried out.

Ratio of Sizes

In designing a floor the architect should notice the special relation between the 6-in. by 6-in. tiles and the $4\frac{1}{4}$-in. by $4\frac{1}{4}$-in. already mentioned, the latter fitting diagonally exactly into the space of the former, the angles touching the centre of each side. The 3-in. by 3-in. again fits into the $4\frac{1}{4}$-in. by $4\frac{1}{4}$-in. ; and a smaller tile, made $2\frac{1}{8}$-in. by $2\frac{1}{8}$ in., again fits diagonally into the 3-in. by 3-in. By using these sizes, and by cutting the tiles, a variety of designs can be carried out without waste.

Tiling on Wood Joists

Where necessity demands, and over small areas, it is possible to lay solid floor tiling on wood joists. A good method is as follows. Between the joists at a convenient level nail battens, and on this fix boarding, at the same time rounding off the upper edges of the joists to be covered. Over the whole lay waterproof asphalt paper and pour in the concrete, which should be reinforced with some type of expanded metal. When the concrete has set the tiles can be laid as on an ordinary concrete floor. Care must be taken to ensure that the joists so covered are thick enough

to take the extra weight without deflecting, and in any case there is always the danger that the surface may crack through movement. The better method is always to remove the joists where possible, and replace with a reinforced-concrete or hollow block floor.

Granolithic Floors

These are concrete floors rendered suitable for heavy wear by the use of an aggregate largely composed of granite chippings. If a granolithic floor is not laid with care it is liable to dust up. Various causes produce this trouble, but the most common faults are improper mixing of the materials or over-trowelling of the final surface, which brings the small-size portions of the aggregate to the surface.

Mix for Granolithic Floors

The Cement Marketing Board suggest that the mix for granolithic floors should be composed of 1 part Portland cement by measure, ½-part fine aggregate, and 2 parts of coarse aggregate ; another good volume measure is 1 cwt. Portland cement, 2 cub. ft. of sand, and 5 cub. ft. of granite chippings small enough to pass a ¾-in. mesh. The topping coat is 1 in. thick, and composed of Portland cement and granite chippings in the proportion of 2 to 5. The granite chippings should be free from dust, and able to pass a ¼-in.-square mesh.

Methods of Laying

There are two methods usually employed in laying a granolithic floor. In the first, the base layer is spread to the depth required, which may be 3 in. or 4 in., on a bottom of hard core. This base layer is brought to a level 1 in. below the finished floor line by means of a straight-edge. The excess water is then removed from the surface, and after being allowed to stand for about two hours the topping coat is added and brought up to the finished level. Two or three hours later the surface should be gone over with a steel float before the cement takes the final set.

As new granolithic flooring cannot be used for about five days after laying, and must be protected, this method may considerably hinder the progress of the work. Even when the floor is set it is liable to be damaged by scratching and wear of workmen passing to and fro before it has attained sufficient hardness.

The second method causes no delay, as the base is laid and left to set like ordinary concrete, and slight damage does not harm it. Careful preparation is required at a later stage, when the topping is to be added, to ensure a proper bond between the two layers. The base should first be washed clean and then thoroughly soaked with water. A mixture of cement and water, of the consistency of thick cream, should then be vigorously brushed on the wet surface, and before this grout has had time

to set the topping coat should be spread and brought to a smooth surface. It is then finished, as before described, with a steel float.

The floor must be protected from weather for at least twelve hours, and care taken to prevent too rapid drying in wind or sun. It is a good practice to keep the floor damp for at least ten days after laying, to obtain the hardest possible surface and freedom from dust.

Precautions in Laying

To prevent cracking due to expansion and contraction the floor should be laid in areas not exceeding 40 to 50 superficial feet. This is done by dividing the area to be covered into rectangular shapes with facing-boards. These boards are trued up and used as gauges for the straight-edges, which rest on them for the purpose of smoothing out the surface.

On completion of the work these boards are lifted out and the spaces filled in. Another way of preventing cracking is to cover the base course with steel-mesh fabric, so that it acts as a reinforcement to the topping.

To prevent slipping, carborundum may be sprinkled on to the topping coat, but the use of driers, such as neat cement and sand, is not recommended as they tend to make the floor dusty. Another method, to gain a good foothold in yards and garages, is to roll the topping coat with a pinhead roller before it has finally set.

QUESTIONS AND ANSWERS

What precautions should be taken when laying Magnesite Flooring on ground concrete?

A damp-proof bitumen coating should first be spread over the floor, and a further precaution consists of diminishing the proportion of sawdust in the flooring compound, and substituting an inorganic filler.

What are the components of a Terrazzo Floor ?

Terrazzo is a compound of crushed marble, aggregate, and cement, the mixture being made rich in cement.

What special precautions must be taken when laying a Terrazzo Floor ?

Terrazzo should be allowed to set slowly, and should be kept moist until hardened. Uneven setting, caused by heat and draughts, may set up strains in the hardening cement which will lead to bad cracking of the floor.

Describe a simple method of making safe a Marble Floor which has worn slippery.

A compound of sawdust and hydrochloric acid, in the proportion of 16 oz. of commercial acid to 1 gal. of water, should be mixed until it forms a sloppy paste, and then spread over the marble to a thickness of about 1 in. and left for fifteen minutes. On removal, the floor should be washed two or three times with clean water.

CONCRETE MIXERS

THE cost of mixing concrete by hand being in the nature of five to six shillings the cubic yard as compared to, say, a shilling by machine, it is not surprising that the latter method is so rapidly replacing hand mixing. In addition to its economy the machine is able to produce better quality and more uniform mixes. Ranging in size from miniature affairs mounted on a wheelbarrow to gigantic batching plants capable of producing several hundreds of cubic yards in a working day, most mixers are described in terms of their input of dry material and their output of mixed concrete per batch, the only exceptions being the few so-called continuous mixers.

As an example a popular size is the 7/5, which takes a charge of 7 cu. ft. of aggregate and cement and delivers 5 cu. ft. of wet concrete at each batch. Similarly, a 5/3½ takes a load of 5 cu. ft. and delivers 3½ cu. ft. of wet concrete.

Types of Mixers

Mixers may be roughly classified as either roller pan, tilting drum, closed drum, batching plant, or continuous machines, but for ordinary requirements the tilting- or the closed-drum type is preferred.

The Tilting Drum (Open Type)

This consists of a roughly conical drum open at its smaller end and arranged to turn about a vertical axle pin carried by a yoke which is suspended in trunnion bearings so that the drum, being provided with a toothed ring around its base, can be rotated by an engine-driven bevel pinion carried on a shaft protruding through one of the trunnion bearings.

Being tilted by a convenient handle the yoke, axis pin, and drum can be inclined at any angle about the vertical without the drum having to be brought to a standstill. Inclined to around 60° from the vertical the drum presents its open mouth to the operator, who can then throw a charge of ballast, sand, and cement into it. Suitable paddles in the interior of the drum stir the contents, and the addition of water allows of the mixing of the concrete, whilst inclination of the yoke, pin, and drum away from the operator allows the drum to tip its contents into a wheelbarrow.

Constructional reasons allow these mixers to be sold more cheaply than the closed-drum type, but they are not usually seen in larger sizes than 7/5. The loading by shovel is necessarily slow so the larger sizes

are fitted in this size with a mechanically operated loading hopper which lifts the charge to such a height that it can run into the drum by gravity. As this form of loading is common to closed-drum mixers, which are usually considered to mix better than the tilting-drum, there would seem to be little advantage in using tilting-drum mixers above hand-loading size, and the 5/3½ is in consequence the most popular.

Unrivalled for Mixing Mortar

The 5/3½ tilting-drum mixer renders its best service in the mixing of mortar, and for this purpose it is unrivalled. It also has the advantage of low over-all height, so that it can be used between the floors of buildings, is narrow enough to be taken through interior doorways, and by a simple process of dismantling into three parts can be readily lifted on to a flat roof, where it can be reassembled for use.

Daily Output of 5/3½ Mixer

It would be unfair to expect a large output from these machines, which cost on the average only one-quarter as much as a 7/5; but any builder doing work large enough to need one of the latter can find good use for a 5/3½, and if it is carefully handled can expect an output of 15 cu. yd. per day of mixed concrete from two men.

Closed-drum Mixers

In the closed-drum mixer, of which several makes are illustrated, the drum is a narrow cylinder of about 3 ft. in diameter and 2 ft. in width, fitted at each end with a cup-shaped plate having an aperture of approximately 1 ft. 3 in. diameter.

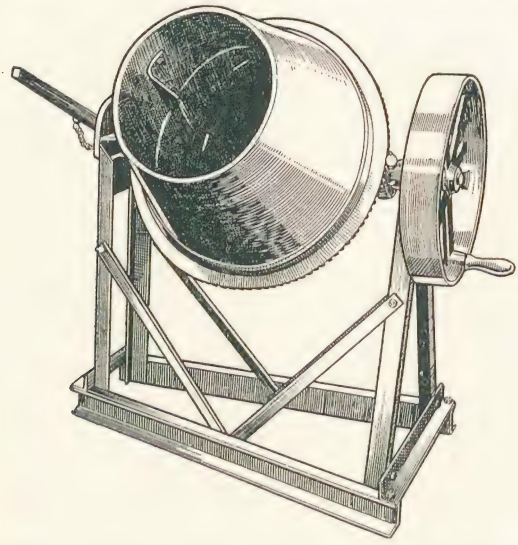


Fig. 1.—HAND-WHEEL CONCRETE MIXER, 50 R.P.M.
This type of mixer has an output of 1½ cu. ft. of wet concrete at each batch.

The drum, which may be of ⅜-in. steel plate or in some cases of a steel casting, is provided with two substantially flat tyre bands which rest on four rollers carried by the frame of the machine so as to provide easy turning of the drum about a horizontal axis.

Pivoted to the frame, on a line near the centre of the aperture in one of the endplates of the drum, is a loading hopper which,

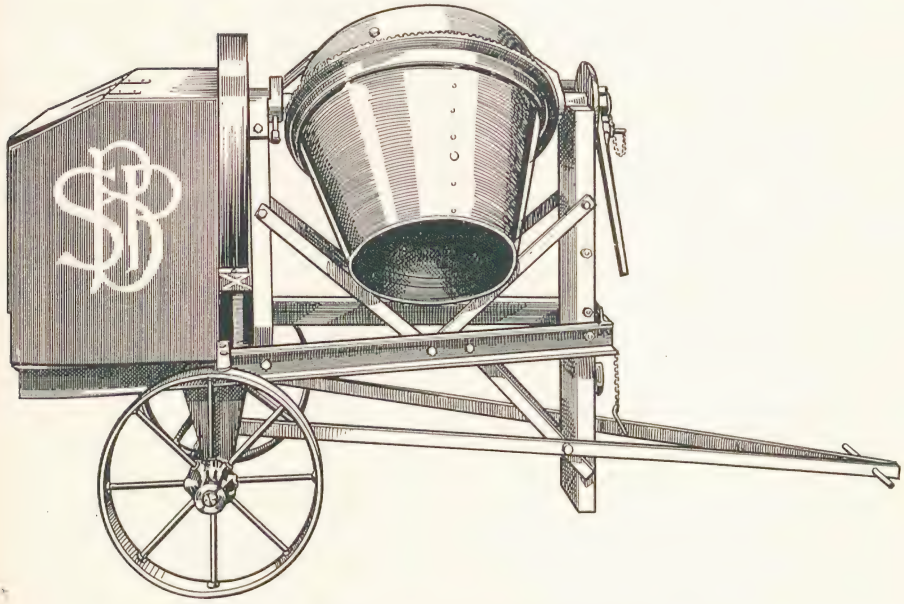


Fig. 2.—A SMALL PETROL-DRIVEN CONCRETE MIXER

This mixer has an output of 3½ cu. ft. of wet concrete at each batch for 5 cu. ft. of aggregate and cement.

by means of wire ropes wound around drums driven by the engine of the machine, can be raised to a vertical or nearly vertical position. This allows the aggregate and cement to fall by gravity into the drum. The latter is provided with paddles fixed to the cylindrical portion in such a way as to carry the material up inside the drum, allowing it to cascade and fall to the bottom at every revolution. On the other side of the drum a hinged chute is arranged which when swung inwards catches the wet concrete in its fall and allows it to slide down the chute and so out to the barrow or skip waiting for it.

On the top of the machine is a water tank from which the required quantity can be discharged through a bent pipe leading into the drum on the loading hopper side.

Points to Watch When Selecting a Mixer

There are a number of different makers of these mixers, and it would be invidious to criticise any particular make. It will be sufficient to point out likely sources of trouble and to leave the reader to form his own opinion of any which he thinks of buying.

Robust Construction Is Essential

Competition has resulted in some mixers being sold at too low a price. This has led to lack of robustness and should be carefully guarded against.

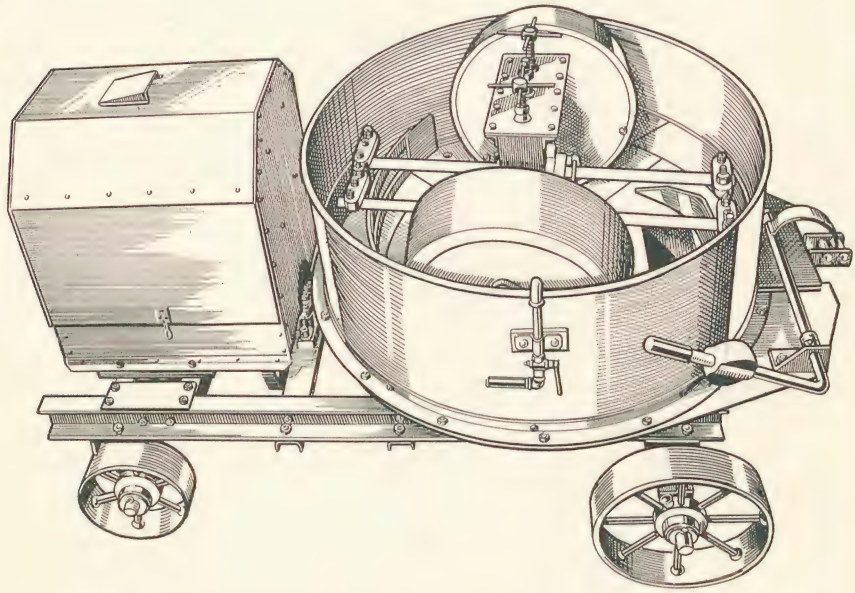


Fig. 3.—A ROLLER-PAN MIXER DRIVEN BY A PETROL ENGINE

The most suitable mixer for lime, sand, mortar, or breeze concrete. The rollers reduce the aggregates to uniform size.

The normal mixer has to stand on rough and uneven ground, has to stand being towed over all sorts of obstructions, and if unsprung must possess a very rigid undercarriage if the whole frame is to remain rigid. If lightly built it will rack, with the result that the track rollers supporting the drum, and the various countershafts concerned with transmitting the engine power to the drum and the loading hopper, will be thrown out of line.

The undercarriage is generally carried on axles, which may be of solid square-section steel or of welded tube. Iron wheels are fitted, two of which serve for steering when the machine is moved. With centre-point suspension of the steering axle one gets three-point suspension. On lifting the loading hopper, which is done by a pull exerted high up on the machine, the whole load of hopper and aggregate tends to turn the machine over on its side, and it becomes necessary to fit some form of adjustable screw or clamp jack which will convert the three-point suspension into a four-point one. Another objection is that, with the iron wheels usually fitted, steering becomes very difficult when either of the steering wheels meets a stone. To use three men to hold a jibbing tow bar, when only one is required with the motor-car type axle, adds to the cost of the concrete.

The track rollers are now usually mounted in pairs on shafts carried at each end in ball bearings.

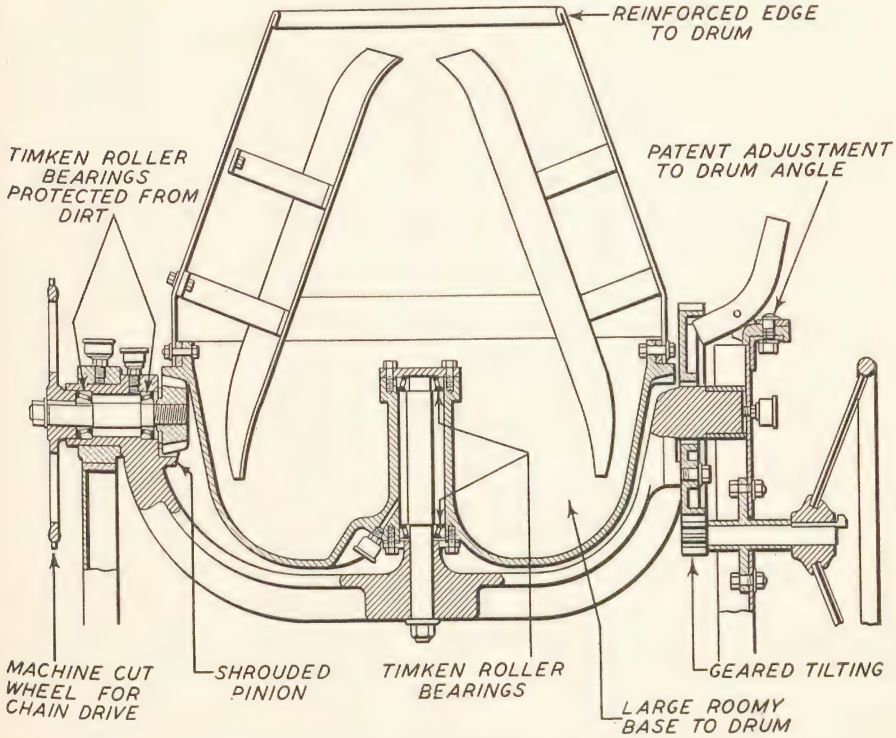


Fig. 4.—DETAILS OF THE DRUM, SHOWING METHOD OF MOUNTING

Although slightly coned so as to keep the drum running centrally between pairs of rollers, these will not function if the machine is not carefully levelled before commencing work, and if the underframe is weak no amount of levelling will keep the rollers level and the drum central.

As the latter is driven by a chain or toothed ring fastened around its outer circumference, side movement of the drum always results in chain or gear trouble.

It is an unfortunate fact that mixer makers always have an excuse when anything breaks, and this applies particularly to ball bearings. If the machine is not level the drum throws a great strain on one bearing of any pair, which is another reason for good and careful levelling. Bearings are occasionally packed with black graphite grease of low quality. This hardens to the consistency of coal and is better forced out and replaced by a good yellow cup grease. If grease-gun nipples are fitted, it should be seen that they are accessible but not exposed to splashings of wet concrete which will result in their being obscured and forgotten.

The Discharge Mouth of the Loading Hopper

In order that the wet concrete in the drum may not splash out, the openings in the endplates are kept as small as possible, with the result that the discharge mouth of the loading hopper is also restricted. Unless this mouth fits well inside the drum aperture when the loading hopper is raised there will be a spill of dry cement, and the clearance being kept small to avoid this, a side movement of the drum causes cutting of the hopper mouth.

As the loading of the drum depends upon rapid discharge from the hopper, any damage to its surfaces is a source of trouble, especially near the lip—which is one more reason for levelling.

Although all makers claim that their hoppers rise far enough to allow the whole of the dry load to run instantaneously down the inside of the hopper, they nearly all fit a rapping device which, striking the discharge lip, vibrates the whole loader. As it is a common thing to see men beating the under side of the loader with a sledge hammer, there would seem to be good reasons for making quite sure, by inspection of a machine in work, that it does give a clean discharge.

Once a hammer has been used the under-side metal becomes pimpled and the discharge becomes worse and worse. A good precaution is to bolt a piece of 9-in. by 3-in. deal to the under side before the mixer starts its job, using cup-headed bolts so as to offer as little internal obstruction as possible.

Raising the Loading Hopper

The raising of the loading hopper is carried out by engaging a clutch connecting the engine to a shaft carrying two winding drums. A wire rope on the drums passes from one to the other by way of grooved wheels pivoted to the loading hopper, or by way of a tube fastened to the same. This latter construction allows the rope to slide slightly through the tube, so that in the event of the rope on one drum mounting on itself, and thus winding in more rapidly than on the other, there is no twisting of the hopper. This method is simple and effective, but if not adopted necessitates the use of a bevel-gear differential action on the winding-drum shaft, and the former would appear to be the better method.

Failure to Declutch Winding Device

As failure to declutch the winding device, when the loader reached the top, would result in the engine trying to drag the loader through the machine, some makes have an automatic device known as a knock-out gear, which performs or should perform the declutching action at the critical moment. If it acts too soon the loading hopper must be moved twice, or it will not have risen to a steep enough angle; if too late the wires will break or the clutch gear be damaged. For these reasons the knock-out gear should be very strongly made, fitted with large, easily

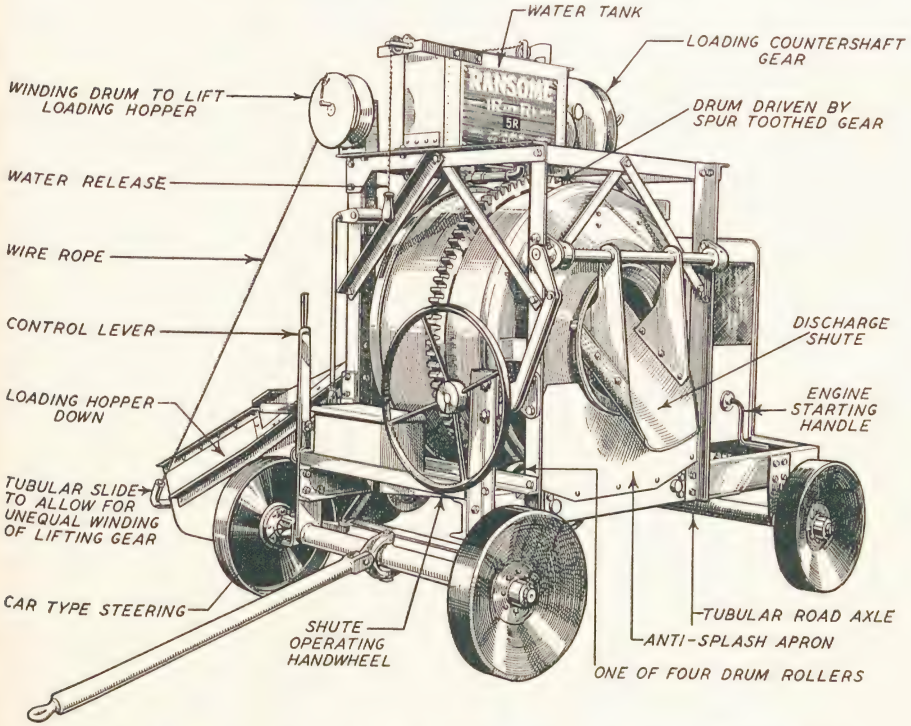


Fig. 5.—A TYPICAL EXAMPLE OF A LARGE PETROL-DRIVEN CONCRETE MIXER
This mixer takes a charge of 10 cu. ft. of aggregate and cement and delivers 7 cu. ft. of wet cement at each batch.

lubricated, pivot pins, and above all be guarded so that stones cannot fall from the raised loading hopper and wedge themselves between the knock-out lever and the main frame.

The Water Tank

The form of the water tank has to satisfy several requirements. It must be as small as possible to keep the head room of the mixer low; it should have some arrangement to allow of continuously uniform discharges of the water; it should be so placed and made as to prevent ingress of stones, which have an unfortunate habit of getting into the more delicate parts of the water system; and should be easily got at when adjustments are required.

In some makes the water is discharged by a syphon action as in some water-waste preventers; in others the water is actually weighed, whilst one or two makers use rubber-seated valves with their stems protruding through packing glands in the bottom of the tank, where they can be actuated by a lever moved by the driver so that he can use his own judgment, assisted by a water-level gauge, as to the amount passed to the

mixing drum. Glass gauges or level tubes are apt to get broken and are easily obscured by splashings of concrete or the blown dust of cement, and other methods seem to be less likely to give trouble.

Unless the tank is totally screened it should be cleaned out once a week, for in its inaccessible position high up on the frame it easily becomes charged with stones and grit which interfere with the operation of the discharge valves.

One type of mixer has rubber-tyred drum rollers and these render it quieter and less liable to jumping than is the case with iron treads. With the latter there is also a tendency for the drum tyres to develop flats, thus changing the circular tread into a polygonal figure ill adapted to free turning on the track rollers. It is possible to have new tyres rolled and welded to the drum, but as they have to be trued in a lathe afterwards it is an expensive process and the ten or twelve pounds spent in this way would be better invested in a new drum.

All mixers wear out, and it is well to inquire the cost of spare parts before purchasing a new machine. All spare parts should be obtainable from the makers themselves, as they have a fund of experience which determines the best type of material to use in such parts as are subjected to heavy wear, and have in addition dies for their accurate manufacture.

The latest practice with mixers is to carry the countershafts as low as possible on the frame, with the result that the clutch which serves to disengage the drum drive from the engine is exposed to more than its share of dust and dirt. Although the mixer engine can be started with the drum " in drive " it is as well to remember that some emergency may demand the instantaneous stopping of the drum, and good guarding of the clutch is therefore essential in addition to frequent testing and lubrication.

Choice of Engine

The choice of an engine for the driving of mixers is generally made by the makers, but a few offer alternatives.

Two-stroke engines are a little lower in price but may be troublesome in inexpert hands.

As all mixer engines are throttle-governed it is also well to satisfy oneself as to the sturdiness and wear-resisting qualities of the links which carry the governor action to the throttle.

The fuel pump should preferably be mechanically driven and of the plunger type as, though apt to leak around the plunger packing glands, they are more robust than those which depend on the vibration of a steel diaphragm operated by alternate crankcase pressure and suction.

The surest way to avoid breakdowns with engines is to keep them clean, so that all the lubrication points can be seen and attended to.

The best method is to purchase lubricating oil in 5-gal. drums, even if it means a few pence extra on each gallon, as it ensures that whilst each

driver has a sufficiency there is not the risk of loss that occurs with a 40-gal. barrel.

There is at present a tendency in the direction of high-speed engines running at 1,000 revolutions a minute or over, instead of the usual 400 to 600 r.p.m., and the need for large gear reductions has brought its own troubles. In one case the makers have had to scrap the design, as the racking of the mixer underframe threw the parts out of line. This point should be carefully investigated, as the parts concerned are expensive and easily spoiled unless carefully designed.

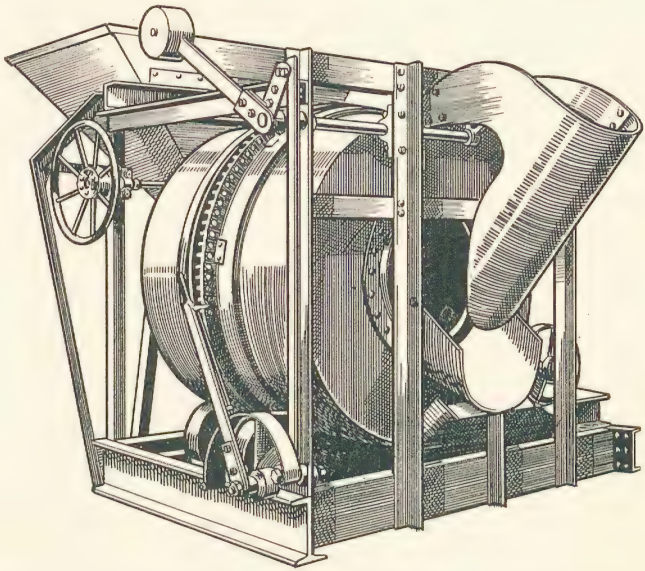


Fig. 6.—ANOTHER OF THE LARGER TYPES OF CONCRETE MIXER
A typical batch mixer with an output of 1 cu. yd. per batch.

To sum up—choosing a substantially built mixer which has not had numerous changes in design will save money in repairs.

The Roller-pan Type of Mixer

Roller-pan mixers have their greatest use when aggregates of large size need to be reduced before mixing, and are therefore of assistance in the preparation of mortar or the making of breeze or brick rubble concrete. They are necessarily heavy, and in the hand-loaded models suffer from a high loading position or a low discharge, but the fineness of the mortar they produce offsets these disadvantages on many jobs. Their portability makes them definitely more useful than older types of mortar pans and they have the additional advantage of serving as concrete mixers or mortar mills, as desired.

A Practical Note on Mixer Outputs

One of the greatest sales points in mixer catalogues is the output of the machine per working day. Whilst it is not suggested that any maker would falsify these figures it is necessary to point out that they are mostly in the nature of records. In one demonstration the engine was carefully tuned; the governor spring tension adjusted to give higher revolutions

than normal, and the men loading were undoubtedly out for a record. If a 10/7 machine will turn out 50 yards of well-mixed concrete a day of eight hours it may be taken as capable of filling all usual requirements.

It must be remembered that the loaders will then have shovelled around 80 tons of ballast into the loading hopper, and it is difficult to believe that many men can be found capable of more. The best authorities demand twenty complete cascades of the mix in the drum, which at the normal twenty revolutions a minute takes around a minute and a quarter, allowing for the introduction of the batch. If the hopper discharge is at all slow owing to dirty discharge lips, this time must be increased.

An Interesting Development

An interesting development in this respect is the use of a drum having several complete helical paddles running from one side of the drum to the other so that the whole batch is passed through to the discharge chute very rapidly. It seems a little difficult to clean owing to the obstruction of the inside of the drum, but may prove to be advantageous when the concrete can be discharged into large-capacity jubilee skips or trucks.

Concerning Continuous Mixers

Many attempts have been made to build efficient continuous mixers, the object being to achieve greater output than is possible when the materials have to be measured into a loading hopper.

As this operation takes place during the time in which the previous batch is being turned over in the drum, it seems an open question whether they can be very much faster, but even if they were, past experience shows that it is very difficult to make a fool-proof feeding device for the cement, with the result that any breakdown to this part of the machine or any inattention on the part of the driver leads to the production of weak concrete, which might be placed in some important part of a structure before the weakness of the mix was detected.

The Double-worm Type

The most recently introduced continuous mixer, which is of German invention and manufacture, uses two worms positioned in the bottom of a sloping-sided bin divided by a partition. The ballast and cement being shovelled promiscuously into the two divisions is impelled by the worms on to which they continually fall into a revolving drum of smaller diameter than is usual with closed-drum machines. Here it is cascaded and ejected in the normal manner. By varying the rate at which the worms turn, which can be done by changing the sizes of certain chain sprockets arranged for rapid removal, the proportions of the mix can be altered to suit the requirements of the job.

Travelling-belt Types

Other machines use travelling belts fed from slots in the bottom of hoppers kept loaded in the same way. Another type blows a fixed charge of cement into the ballast, but it seems that it is a little early for the small builder to adopt these designs. They are at present chiefly suitable for use by larger contractors.

Conveying a Mixer to the Site

The transport of mixers is not always an easy matter.

Police regulations debar the towing of iron-wheeled vehicles behind a lorry ; the wheel bearings of the average mixer are plain steel to steel or cast iron and ill adapted to speed, and the best method is to hire one of the specially low-built lorries known as low loaders.

Being fitted with a winch and slides, these allow of the mixer being drawn safely from the ground to the lorry and vice versa.

A Money-saving Device

As hire charges for these lorries are about 7*s*. per hour, and as such lorries cannot easily be obtained in all districts, use is sometimes made of a separate towing frame built from two lengths of 6-in. by 2-in. rolled-steel joist and provided with pneumatic-tyred wheels with detachable axles.

The joist frame being placed beneath the mixer, it is jacked up the few inches necessary to allow the pneumatic wheels to be slipped on, and then lowered until they ride. Using this device, the writer has towed 14/10 mixers at speeds of twelve miles an hour, and the first cost of something under ten pounds has been saved over and over again.

Using Concrete Mixers

The approved methods of using different types of mixers, with practical notes on running and maintenance, will be found in the appropriate section of Volume III.

QUESTIONS AND ANSWERS

What is meant by a 7/5-size Mixer ?

This means that the mixer takes a charge of 7 cu. ft. of aggregate and cement, and delivers 5 cu. ft. of wet concrete at each batch.

What are the main types of Concrete Mixers ?

1. Roller pan. 2. Tilting drum. 3. Closed drum.
4. Batching plant or continuous plant.

What is a convenient type to use for mixing Mortar ?

The 5/3½ tilting-drum mixer, because it can be used between the floors of buildings and is narrow enough to be taken through interior doorways. It is also easily dismantled, so that it can be lifted on to a flat roof, where it can be reassembled for use.

GENERAL NOTES ON FORMS FOR CONCRETE WORK

IN the present article we give notes dealing with the more general aspects of formwork. Later articles will deal in greater detail with forms for special purposes.

Closing Up Joints

The joints of forms should be closely clamped together, and where sections are not truly fitted in erection the cavities should be stopped with either putty or cement if there is time for it to harden.

Failing to do this, water carrying a percentage of cement will get away from the concrete, leaving a weak mixture. External angles, especially, should be dealt with in the foregoing manner, or they will be broken when the forms are dismantled.

Projections Should Be Bevelled

Where projections are made on the forms, recesses are made on the castings. Therefore, should a sunken panel be required in the casting, a raised panel must be fixed to the forms. All edges of the projections must be bevelled on the average $\frac{1}{8}$ in. in 1 in. to allow easy withdrawal. Without this the arris of the panel will certainly be broken away.

Making Chamfers in Concrete

Where chamfers are to be left on the concrete, bevelled strips should be securely nailed to the forms. This work is often carried out on a pier and panel system, since the chamfers so formed give easy movement to the forms, especially at the internal angles.

Holes in Concrete

Concrete constructional work often calls for holes to be formed in the concrete for holding-down bolts, etc. For such work, boxes should be made of $\frac{1}{2}$-in. thickness wood, using external dimensions for the size hole required. This wood should be free from knots and with a fairly straight grain. When the concrete is sufficiently hard the boxes must be split out, and this can be easily done if the above instructions are carried out.

Strength of Forms

Failures often happen through weak forms being made. Insufficient ledges or braces to the forms are the cause of many failures.

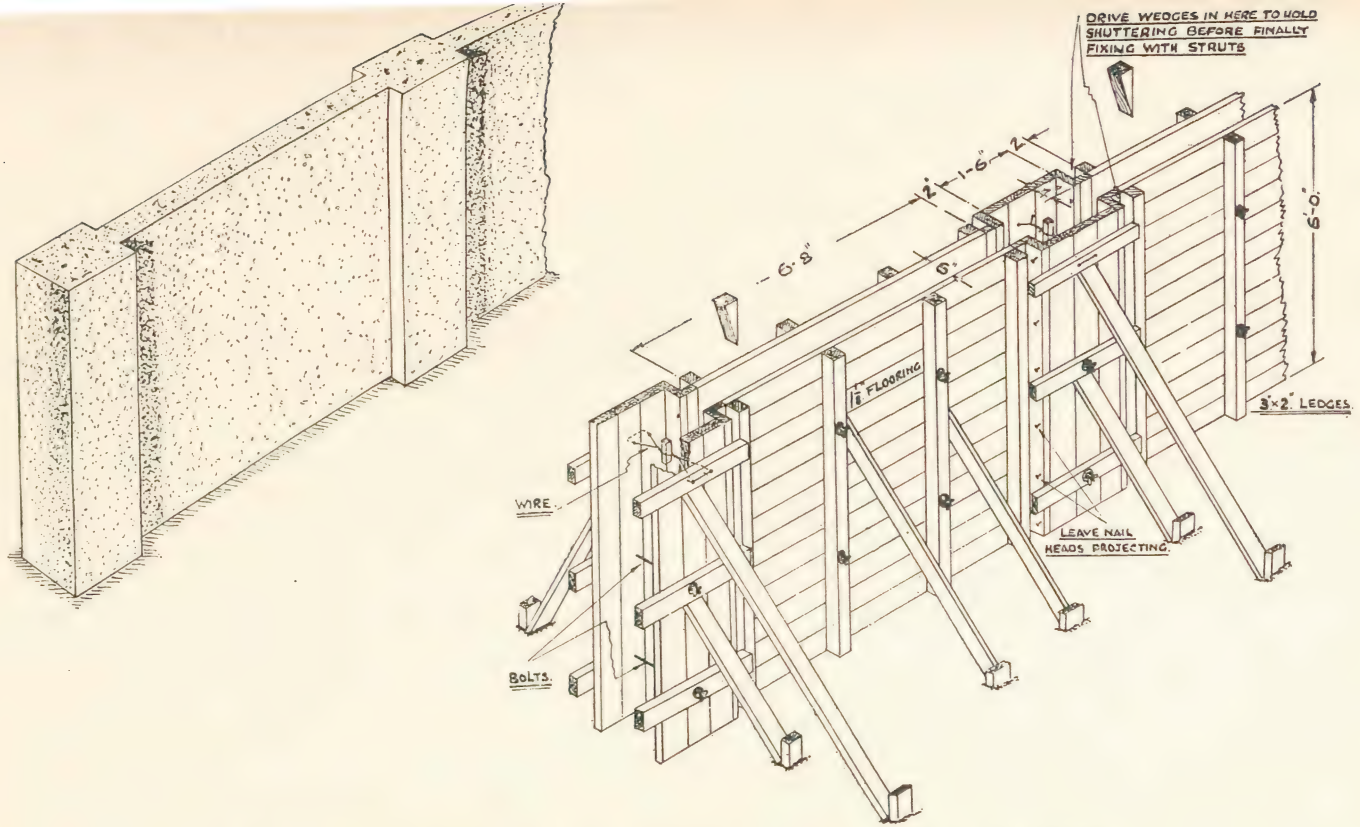


Fig. 1.—METHOD OF ERECTING SOLID CONCRETE WALL ON PIER AND PANEL SYSTEM

The wall is to be 6 ft. high and 7 ft. between piers. Note arrangement of the wire ties in the piers. The forms are fixed together, so as to be easily dismantled without being injured.

When to Dismantle Forms

On no account should forms be dismantled before the concrete is thoroughly hard, but there can be no hard-and-fast rule as to the time limit for dismantling, since the climatic conditions play a very important part in this type of construction.

BOARDS AND BATTENS

Timber Employed

Forms for good-class work are usually constructed of 1-in. tongue and groove flooring. The boards should be thoroughly clamped together, and well ledged at 18-in. centres. Ledges should be 3 in. by 2 in. and, if possible, free from twist, as it will be found when fixing that twisted forms give trouble. For some jobs rough boards will be quite enough, and it may be found necessary for them to be 1½ in. thick. If sufficiently ledged, flooring has proved itself over and over again. Ordinary deal wood is most suitable for making forms where the concrete is to be poured, as struts and braces can be easily fixed. Where it is necessary to nail here and there, these nails can be easily withdrawn when dismantling.

All forms should be made from timber free from dead knots and big shakes as far as possible, as they are a source of nuisance when the timber has to be used over and over again.

Timber for Circular Forms

Timber for making circular forms should be more carefully selected than that for straight work, since it is very important to keep these free from twist to ensure a good job.

The ribs should be 2 in. thick, while the lagging should not be too wide, 1 in. being most suitable, but, of course, the width should be governed more or less by the curvated segment.

METHODS OF FIXING

Use of Nails

When fixing forms the most simple methods must be adopted. Nails should be used sparingly, as they tend to ruin the timber when used many times, but where it is necessary to use a nail do not drive the head home. It should be left projecting far enough for the claw hammer or pincers to obtain a grip.

Screws

If screws are used it is a good plan to use small galvanised washers behind the head to check the screw head embedding into the wood. The grease pot will also assist, since it is recognised that rusted screws are often a source of trouble when dismantling.

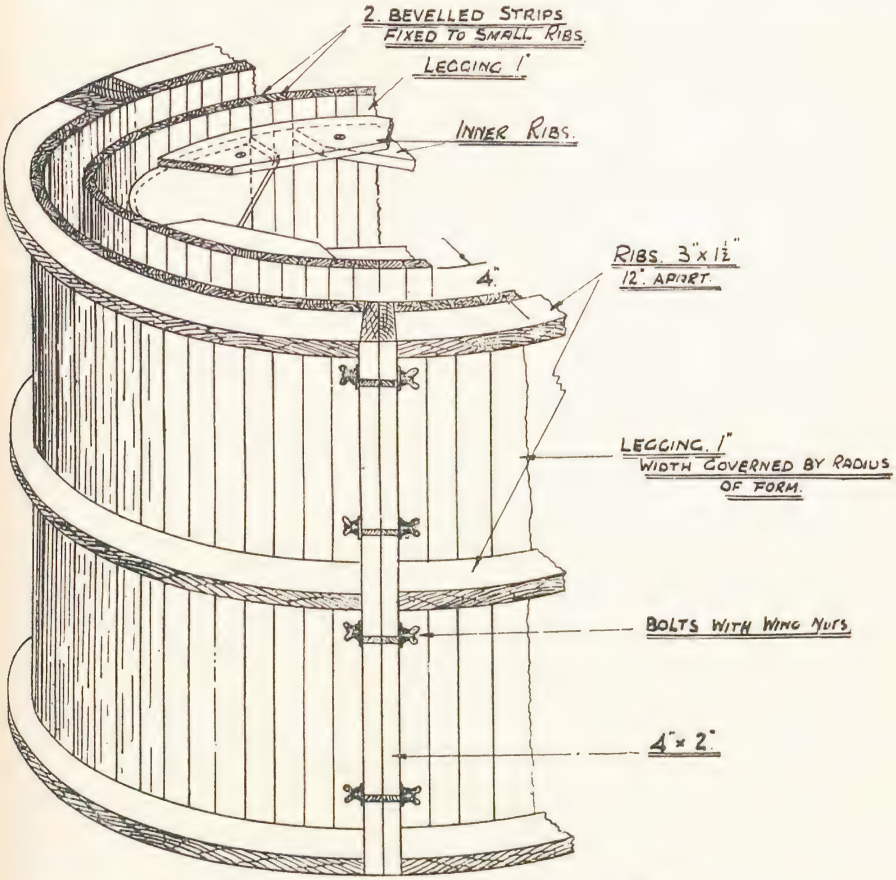


Fig. 2.—METHOD OF ERECTING CIRCULAR FORMS

Note the strong construction, with ribs both inside and outside the forms, and not more than 12 in. apart. The principles of construction are the same whether the forms are for making a concrete tank, water tower, or stack. Ease of dismantling is again a subject for forethought, as it should be whenever forms are being put together.

Use Wedges Wherever Possible

Wedges should be used wherever possible in preference to any other type of fixing. Many jobs have been carried out without a single nail or screw being used.

The Importance of Sufficient Strutting

One cannot emphasise too much the importance of sufficient strutting for all forms.

Concrete, plus the necessary rodding and tamping required to consolidate it, exerts an immense pressure against the forms. Should they

give way through insufficient strutting, then there is no remedy other than to rebuild.

How to Erect Solid Walls—Pier and Panel System

Solid walls of concrete can be erected by various methods of fixing the forms. For instance, suppose a wall is required to be erected on the pier and panel system, the dimensions being as follows : 7 ft. between piers, the piers 18-in. face with 4-in. projection, and the height 6 ft. over-all (see Fig. 1).

Amount to Cast in One Operation

It is quite practicable for this wall to be cast in one operation so far as height is concerned, but where high walls or piers are to be erected, the lift should not be more than 3ft. at one operation to avoid excessive side thrust.

A Practical Example

To carry out the construction of the forms for this dwarf wall, the pier forms should be in three sections, while the forms for the panel can be in one section.

The pier sections would be one for the full width of the face, and one on either side returning the internal angle by 2 in. These would be temporarily fixed together and thoroughly strutted in position, thus leaving the length of the panel form to be 6 ft. 8 in., this also should be temporarily fixed to the pier forms and strutted. The arrangement is seen clearly in Fig. 1. A similar process can be carried out on the other side of the proposed wall.

Ties Between Two Sets of Forms

Bolts can pass through the two sets of forms to keep them from spreading when the concrete is poured, or wire ties can be utilised in a similar way and twisted taut until the necessary distance required between the forms is obtained.

Using Tie-bolts

Should bolts be used they should be greased before the concrete is poured, as they must be withdrawn when dismantling the forms, and the holes left in the concrete through their withdrawal filled in at some later time.

Using Wire Ties

In the case of wire ties being used, these can be cut and left flush, but may cause rust stains on external work unless cut back and filled.

This type of fixing would be easy to dismantle without injury to the forms.

Ceilings and Beams

Similar methods to the foregoing can be utilised in fixing forms for ceilings and beams, but in this case, of course, double shuttering would not be required.

MODERN TIMBER CONSTRUCTION

PART I.—SURVEY OF TYPES WITH CONSTRUCTIONAL DETAILS

THE Ministry of Health in a recent communication states that "while it is contemplated that the model by-laws may be modified to suit local conditions, it will be found that—so far as by-laws govern the construction of the external walls of domestic buildings—the use of timber is everywhere allowed."

Fire Risk

One of the commonest arguments advanced by critics against timber construction, and especially timber houses, is the fire risk. Recent statistics dispose entirely of this bogy, for it is a bogy when one considers the amount of timber construction in a normal brick and tile structure. Both have wood floors, wood roof timbers, wood internal partitions, wood doors, and wood windows, the only difference being that one has wood walls and the other brick. It has been pointed out that a fire that is near enough and hot enough to ignite a wood wall is also hot enough to shatter a window and catch the wood linings, and that nearly all domestic fires are due to internal causes.

An interesting result emerges from a survey, made in America by the National Board of Fire Underwriters, of over 1,000,000 houses. Of these, 75 per cent. were of wooden construction, and the survey showed that whereas there were 1·65 fires for every 100 of these, there were 2·43 fires in every 100 brick ones. This unexpected result was considered to be due to the forcing of heating plants in brick houses, due to the poor insulation quality in comparison with wood.

Lloyd's approximate rates for fire insurance on buildings wholly constructed of Canadian cedar are stated by the British Columbia Timber Commissioner to be :—

Building and contents, $\frac{3}{4}$ per cent. up to £5,000.

Comparative Costs

This is perhaps the crucial factor in overcoming the prejudice which undoubtedly still exists in the minds of many prospective home builders. The conservative mind will never be tempted to experiment with wood in this country until it is conclusively assured that it is not only "as cheap" as brick, but definitely cheaper. The British Columbia Timber

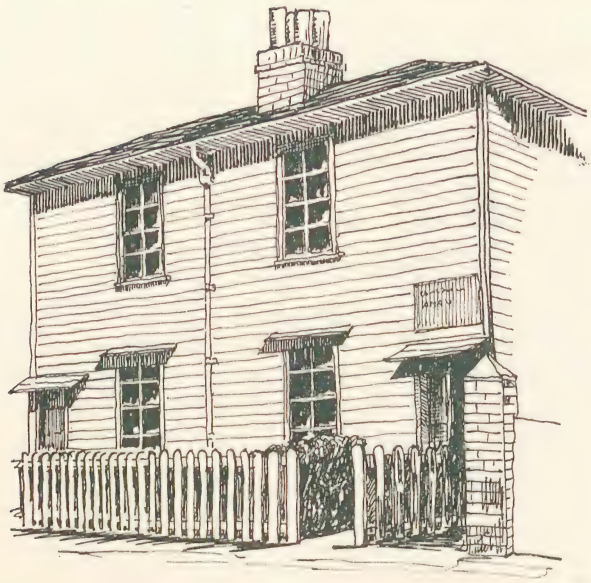


Fig. 1.—ENGLISH WOODEN HOUSE OF EARLY NINETEENTH CENTURY

Commissioner asserts quite definitely that a wood house is 25 per cent. cheaper than a similar one built in brick. But comparative costs are always difficult, especially if one of the materials is unfamiliar. A contractor who builds one wooden house may find that the extra supervision and instructions necessary will put up his labour costs to nearly those of a brick building, but if he is building fifty or so, these costs, after the first few houses, will show a very rapid decline as the workmen become familiar with the material; the plasterer, and so time for drying out, will also be eliminated, as well as the bricklayer and other trades which have to wait one upon another.

The practical method, therefore, is to adopt a standard suitable for England, as has been done in other countries, and familiarise the workmen with its details; where this is once done there is no reason why savings up to as much as 30 per cent. should not be made, as they have been in Sweden and Germany, where the standardisation of these structures has been reduced to a science. Homes have already been built in England at a total cost of 9*d.* per cubic foot. The costs of the Swedish examples are approximately £650 for the larger (Fig. 3), and £350 (Fig. 4). These prices are for the wooden structures above the foundations, the cost of which, as well as of plumbing, must be added.

Considerations of cost must include maintenance, and timber houses require painting or re-treating with some preservative, unless the outside is entirely covered with Canadian red cedar or oak. The result of an experiment by the L.C.C. in 1927, on their Becontree Estate, with pre-fabricated timber houses from Sweden, has shown that these timber houses have given less trouble in maintenance than the brick ones.

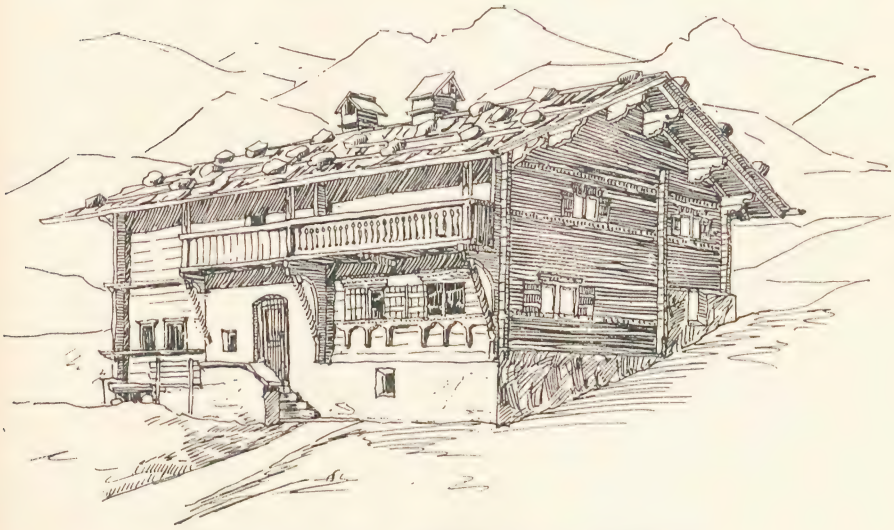


Fig. 2.—WOODEN CONSTRUCTION IN SWITZERLAND
Showing inner partition walls carried out to support eaves and balcony.

Two Methods of Construction

As there are two different main sources of softwood supply, so there are two methods of construction, which may be broadly classified as hollow and solid. Such a classification is not clear cut: certain wall types may be partly hollow and partly solid, but the most general types of modern American buildings are dependent on a framed structure of posts and struts for their stability, while Scandinavian buildings carry their weight on solid wooden walling. Both types employ outer and inner coverings and insulating materials, so the wall may be considered as comprising an internal portion to support the structure, covered with sheeting materials to protect it from damage by weather.

The Design of Timber Buildings

In planning timber buildings the architect has a great freedom, for wood adapts itself to all shapes except the curve. Semicircular door heads and bull's-eye windows can be built up, but they are not natural to the material, and in countries with a long timber tradition they are absent. In Scandinavia, windows are semi-hexagonal in preference to semicircular, and door heads are made up on rectangular forms. Semicircular bay windows, again, are less satisfactory than those with definite angles. Modern practice tends also towards a flat-roof type of structure, though there seems to be nothing more than a passing fashion in this. Traditional timber roofs can be as flat as in Switzerland or as steep-pitched as in Russia or Scandinavia, and modern roofing materials extend from

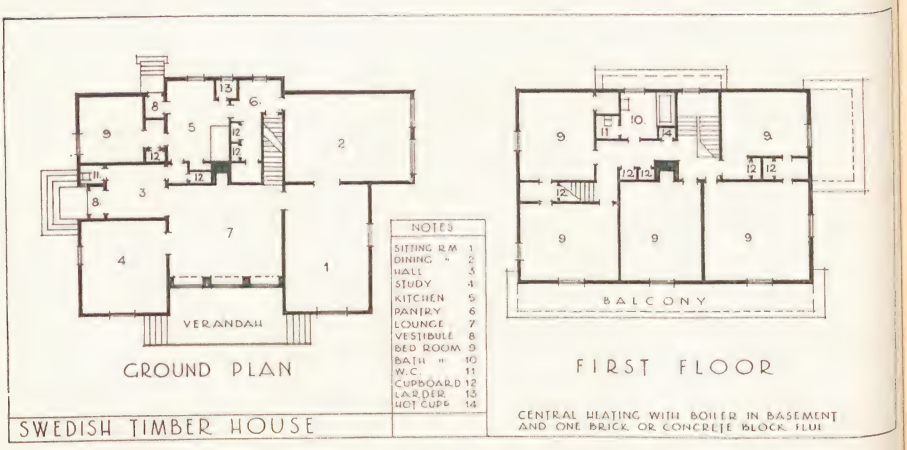


Fig. 3.—PLAN OF SWEDISH TIMBER HOUSE

cedar shingles through slates to tarred felt and asbestos, to suit all types of design.

How differently the temperaments of two countries, each working in the same material, can express themselves in design, may be seen from the sketches of wooden houses in England and Switzerland (Figs. 1 and 2). Each is a cottage, each was built about the beginning of the nineteenth century, and each is built—with the exception of the English cottage roof—entirely of softwood. The Swiss châlet fits perfectly into the mountain landscape, and the English cottage into the village street. These examples illustrate the importance of designing naturally for the requirements and situation. Foreign elements may be borrowed, but must be assimilated before they can be made useful, especially as modern timber construction has made greater advances abroad than in this country.

The example of the large house from Sweden illustrates several points of good timber design (Fig. 3). The house is central-heated throughout, with an open fire in the lounge and in one bedroom. Both these fires are for appearance rather than heating, and the important point to be noticed is that flues are reduced to a minimum and brought up in one stack through the centre of the roof. The plan is flexible with regard to the arrangement of living-rooms, but main walls divide the ground floor into three definite portions, which allows the structure to be well tied together. First-floor external walls can be set back without considering heavy joists to carry them below, and advantage is taken of this to provide balconies. The ground floor is raised some 3 ft. above the ground, and a veranda opening from the lounge forms a pleasant feature. The basement (not shown) contains cellarage, heating and washing accommodation, as well as in many cases a garage, approached down an

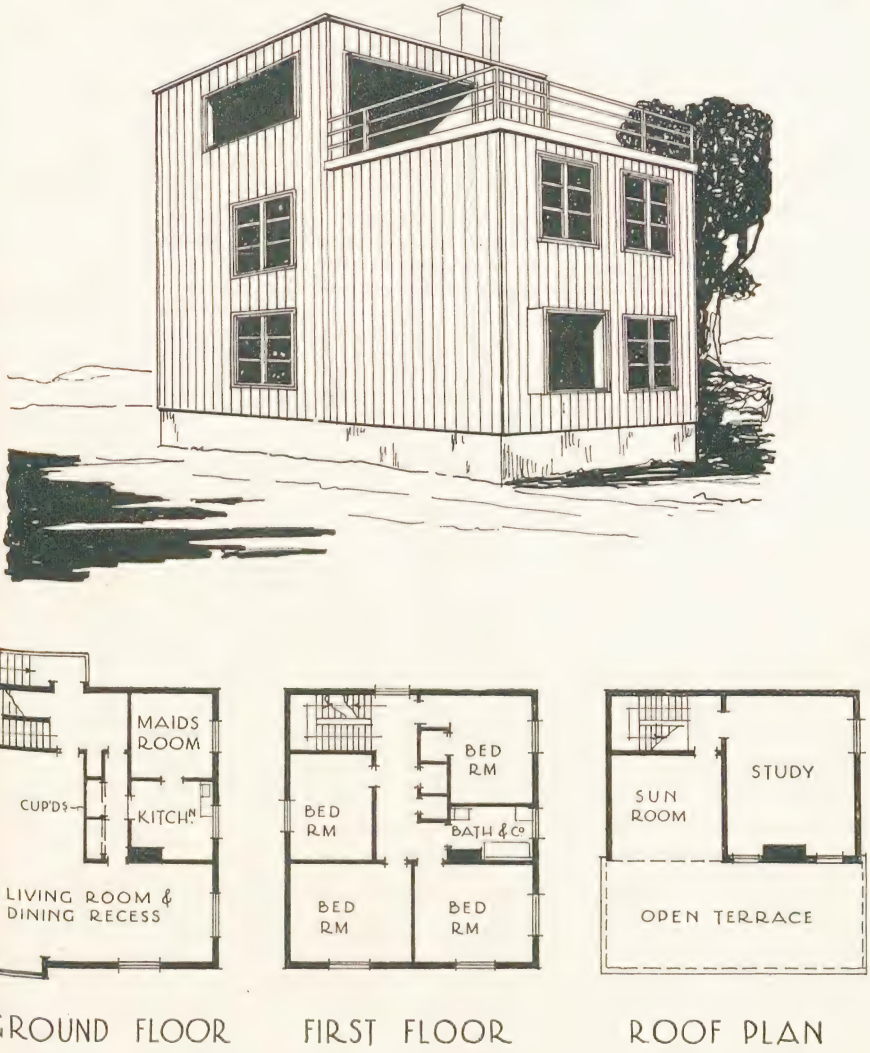


Fig. 4.—SMALL SCANDINAVIAN VILLA

easy gradient. The roofing of the rectangular first floor is an easy matter in any style that may be desired.

The other Scandinavian example is a small villa which could be erected either on the spot or from standard sections (Fig. 4). The roof terrace and sun room, with study for quiet, will be appreciated more and more in this country, and in wood can be obtained at practically no extra cost, whereas in any other material the cost of the additional cube would be considerable. The living- and dining-room usually has a curtain or light screen that can

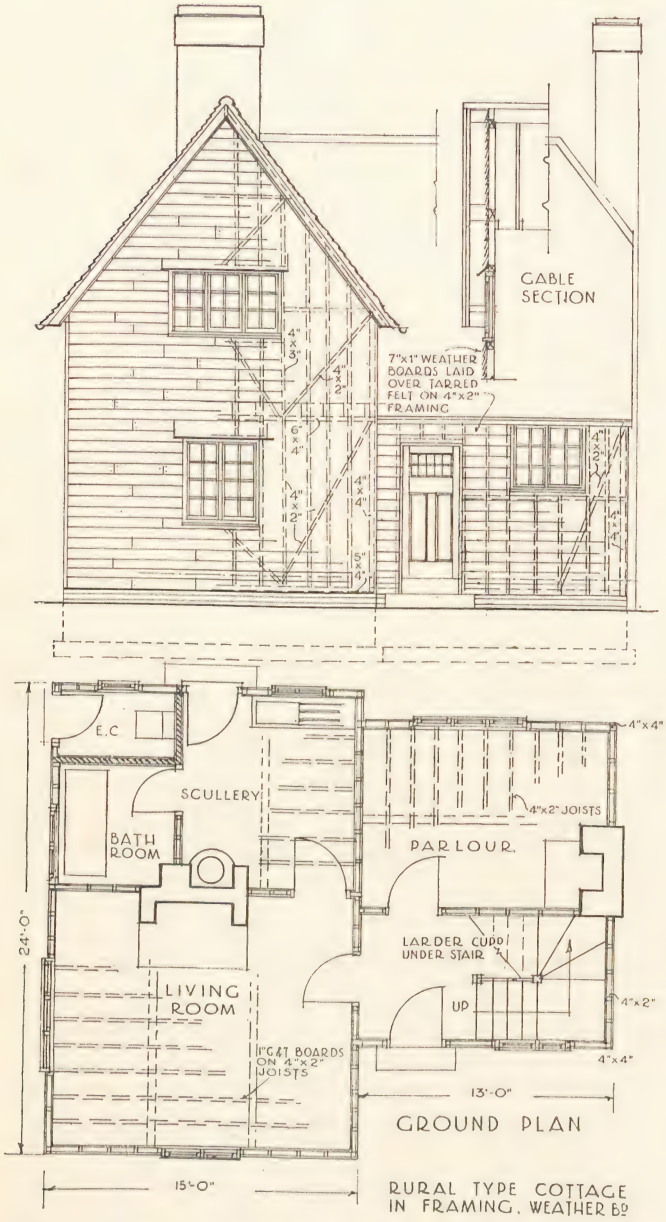


Fig. 5.—RURAL TYPE COTTAGE IN FRAMING WEATHER-BOARD

be pulled across the dining-recess during the laying of meals, and although a maid's room is provided it is a plan that would be very labour-saving as a servantless house. Here, again, the central-heating plant is in the basement, and only one flue is required.

The third is an English example which is suitable for average needs but still clings somewhat to the form of brick and tile (Fig. 5). The two flues are an unnecessary expense, and no use has been made of the basement space; the three bedrooms above will all probably be heated with open fires, and bath water in the scullery copper. Generally, the plan is good, with adequate ties between the walls, and the external appearance is typically English, but it is more expensive to build in timber than the Swedish

example, and far less easy to erect in pre-fabricated standard sections.

Foundations

To preserve the timber from decay, all wooden structures must be raised on a foundation above the ground. The simplest way is to lay the cills on creosoted wood pegs driven into the soil at intervals. This method is only employed for the most temporary of structures, and even in hutting and farm buildings is usually replaced by brick or concrete piers.

The proper method, for all permanent timber structures to be occupied as dwelling-houses, or for other human activities, is to excavate for a brick or concrete foundation for all the external walls and main cross-partitions, and to carry these up at least 1 ft. above the surface of the ground (Fig. 6). A layer of concrete should be spread over the whole site within the external walls. It is a common practice to increase the accommodation at small extra cost by digging down sufficiently deep to make the space beneath the ground floor a suitable height for a cellar. In Sweden the basement cellar is an important part of the structure, contains, besides the garage and central-heating plant, a wash-house, larder, and workroom. These rooms are ventilated through small openings punched in the concrete basement walls between the level of

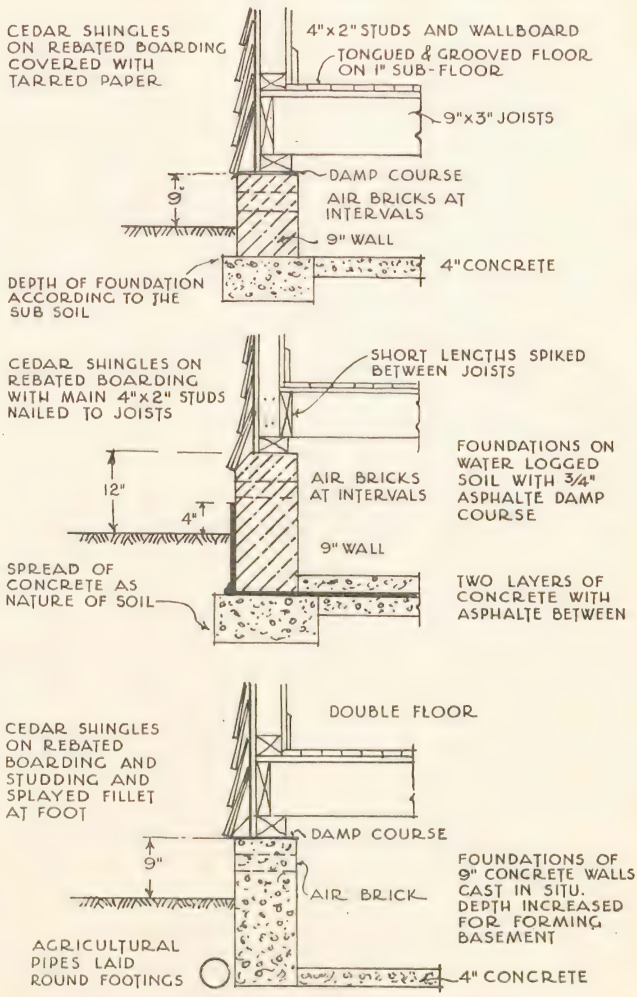
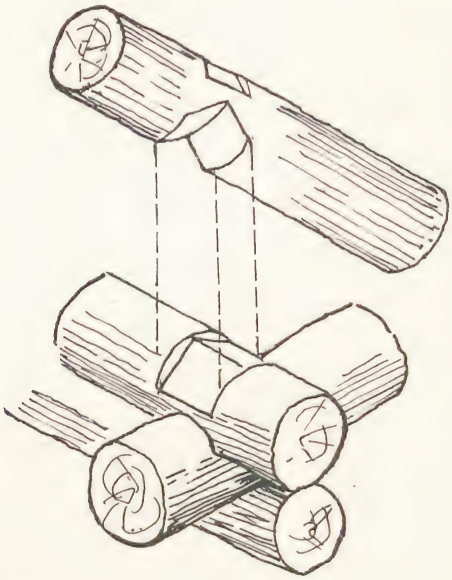


Fig. 6.—VARIOUS TYPES OF FOUNDATIONS



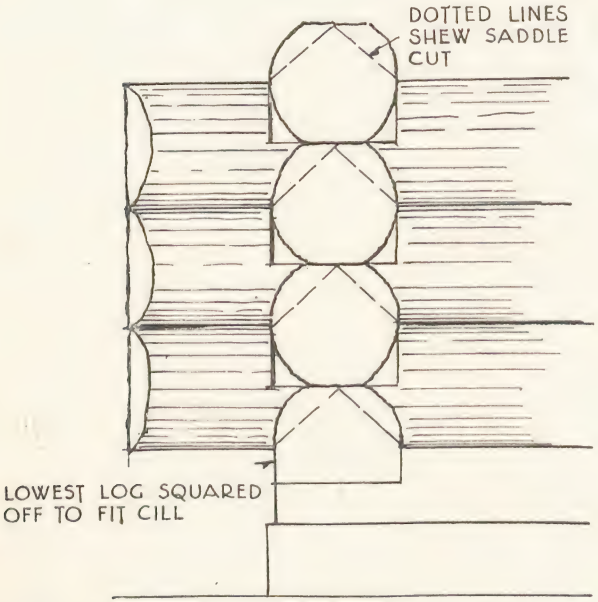


Fig. 7.—LOG CABIN CONSTRUCTION—JOINTS AT ANGLES

the ground and the cill of the ground-floor joists.

If the Site Is Waterlogged

If the site is waterlogged or liable to flooding, it is better to provide both vertical and horizontal damp-courses, not only to the walls, but also to the concrete floor of the basement. For a normally damp soil, two thicknesses of concrete with asphalte sandwiched between should form a sufficient protection, but if the site is liable to flooding, a proper reinforced basement slab must be provided, calculated to withstand the upward thrust of the water.

Another Precaution against Damp

Another simple form of precaution against damp, in districts where springs may run underground, is to lay agricultural drain pipes round the base of the foundation walls. This will lead spring water away from the building and prevent it ponding up against the upper walls if the site is situated on a slope. On exposed sites, or if the building is small and light, holding-down rag bolts should be built into the foundations to receive the cills of all external walls. These rag bolts will have to pierce the damp-course, and

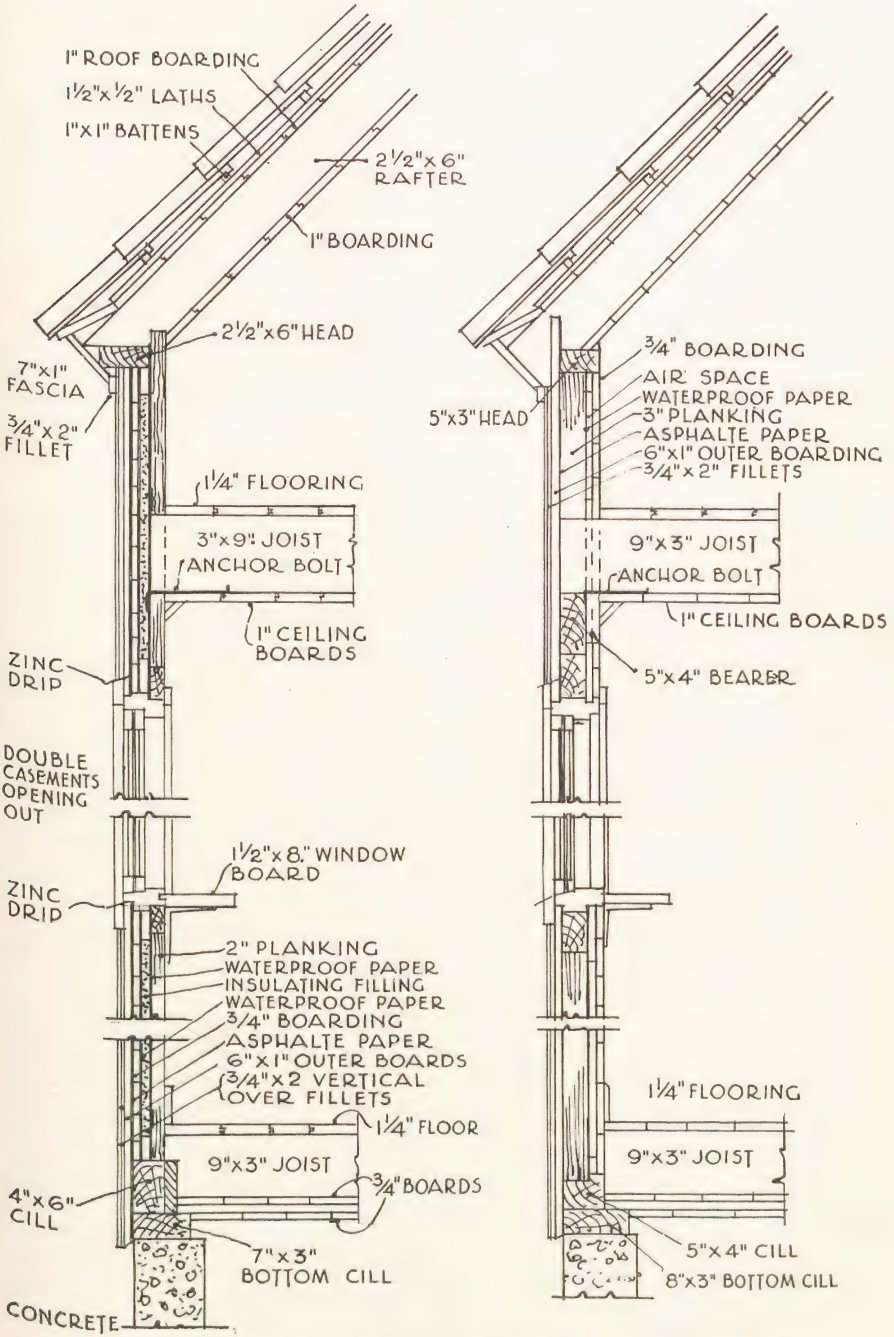


Fig. 8.—TWO METHODS OF SWEDISH OUTER WALL CONSTRUCTION

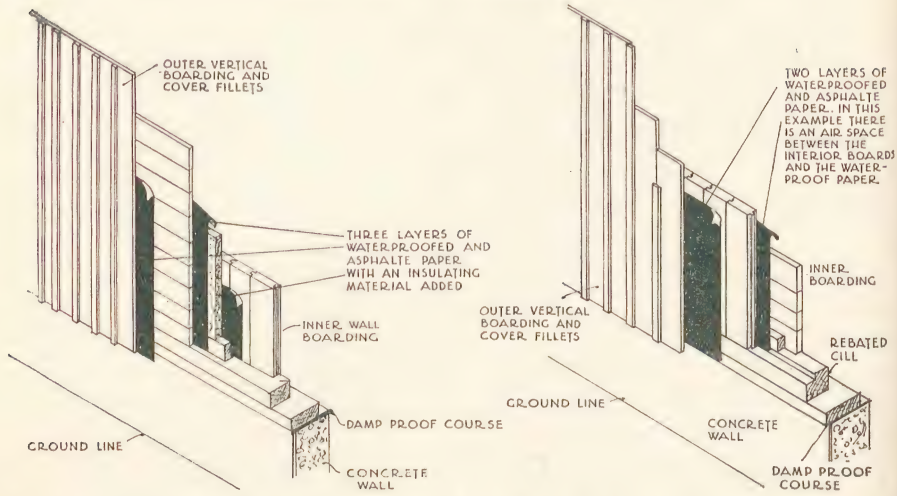


Fig. 9.—ISOMETRIC SKETCHES SHOWING THE METHODS OF PREVENTING TEMPERATURE CHANGES IN WOOD BUILDINGS

special care must be taken to render the holes waterproof by either red lead or bitumen mastic.

CONSTRUCTION

A Simple Log Cabin

Originally, timber structures were built up of solid tree trunks roughly notched at the ends, with the butts projecting beyond the angle, a tradition which still persists in the log cabins of America to-day (Fig. 7). The construction of these log cabins is one that can be carried out with the simple tools available to a lumber man. The logs are flattened off on the top and bottom, after having been stripped of their bark, to provide a bearing, the cill log being hewed on the two sides and bottom to sit firmly on the foundation. At the angles of the building, the logs are crossed, leaving the butts projecting about 18 in. each way. This crossing is done by cutting a wedge-shaped piece out of the under side of each log at right angles to its length, about half the depth of the baulk. The upper side of the log is shaped down parallel to its length to fit into the cut of the one above, and thus the walls are built up of alternate layers placed at right angles to one another. At intervals, for further stability, the logs are pinned together with drift bolts.

The joints between the logs are caulked with oakum, moss, or cement after the work is completed, and this caulking has often to be repeated, as the logs shrink after fixing. Holes are left for doors and windows, which are roughly squared, and irregularities made out with boarding. Such buildings are economical to erect only in forest districts where timber is abundant but labour and means of conversion scarce.

Where machinery is available, the tree trunks are often superseded by squared timbers morticed together at the ends, with the baulks laid horizontally, but buildings so erected are not wholly watertight or proof against changes of temperature. Modern practice has adopted the method of building up the walls in a number of skins, either as a solid structure or with studding covered with various layers of boarding.

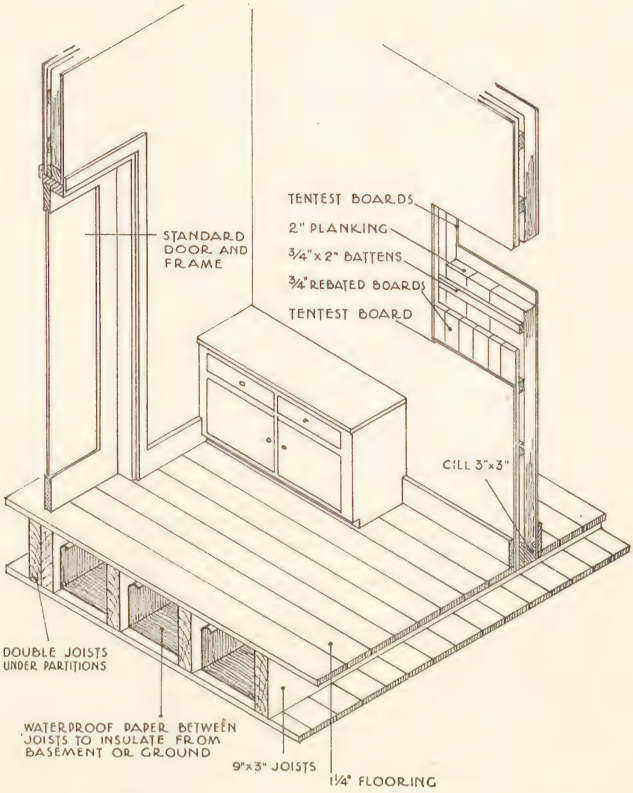


Fig. 10.—INTERNAL PARTITIONS OF HOUSE WITHOUT PLASTERED WALLS

Solid Construction

This method is employed in Scandinavia almost exclusively, the walls being built up in a number of skins of various materials and thicknesses. The arrangement of these skins varies considerably, but the main constructional part of the wall is always a thickness of solid rebated planking 9 in. by 2 in. or 9 in. by 3 in. This core is usually fixed vertically, but several types employ the framing horizontally. Into this solid framing are fixed the floor joists and internal partitions, and it also carries, in places where there is a pitched roof, the feet of the common rafters.

The illustrations show two types (Fig. 8). In one, the wall is composed of 9-in. by 2-in. rebated planking covered with insulating paper. Next comes a space filled with some sound- and heat-insulating material, such as sawdust or seaweed. On the outside of this is a layer of ¾-in. grooved and tongued boarding covered on the side next the sawdust with insulating paper, and on the outer side with asphalte paper. Over this is a final outer covering of vertical 6-in. by 1-in. boarding, having the joists covered with ¾-in. by 2-in. laths.

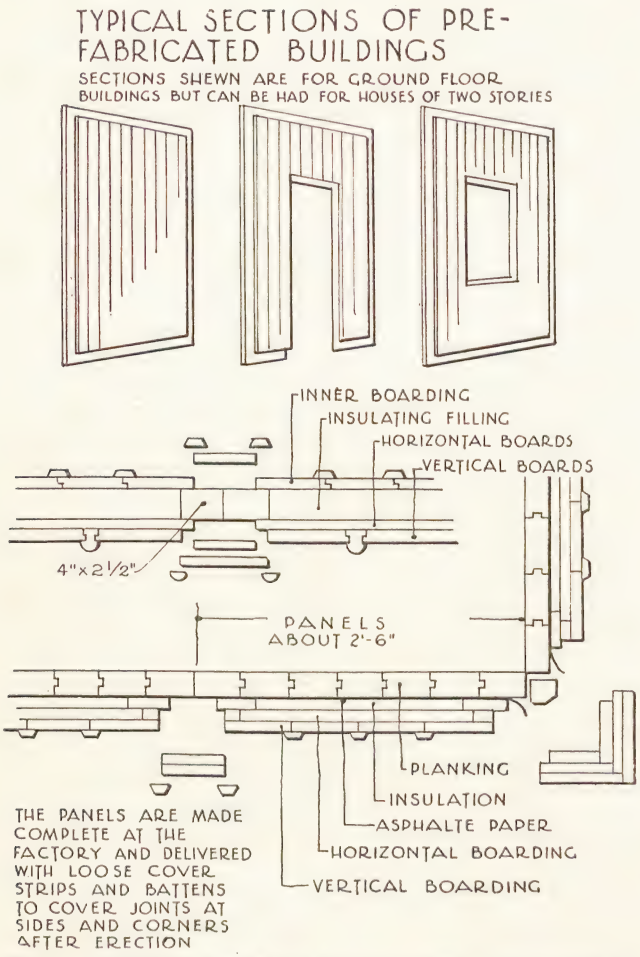


Fig. 11.—SWEDISH SYSTEM OF STANDARDISED WOOD BUILDING

The second example differs slightly by having a ¾-in. grooved and tongued boarding laid horizontally as an inner sheeting, and behind this is an air space before coming to the main planking, which is composed of 9-in. by 3-in. rebated planks, covered on one side with asphalte, and on the other with insulating paper. The outer skin is the same as in the other example, being composed of 6-in. by 1-in. planking, with 2-in. by ¾-in. laths on the vertical joints.

The outer laths are sometimes applied, as shown, to the face of the butt joints in the boarding, or may be rebated or grooved to take the edges of the planks themselves.

Window and door openings are left in the main framing and the joinery fitted in afterwards, much in the same way as with an ordinary brick building.

The total thickness of such walls is about 6 in. (Fig. 9) and, though the arrangement of the papers and planking, with or without air spaces, is varied by almost every designer, the total thickness remains the same. The inner walls (Fig. 11) are usually composed of 2½-in. by 4-in. studs or planking covered with boarding or wall board, usually having an asphalte paper or insulating paper placed on one side of the framing beneath the finished wall material.

Such construction can be carried out on the spot, but recently con-

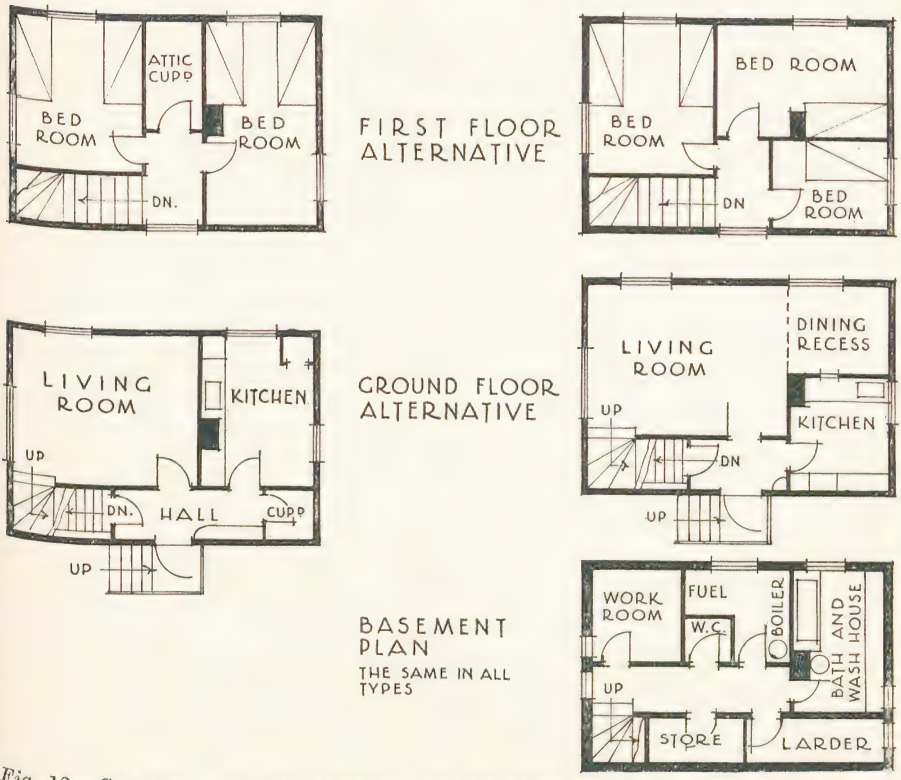


Fig. 12.—SECTIONAL HOUSE MADE UP OF PRE-FABRICATED WOODEN SECTIONS, WITH ALTERNATIVE ACCOMMODATION

siderable progress has been made with pre-fabricated buildings put together in factories and delivered in sections to the site.

Pre-fabricated Structures

These sectional houses (Fig. 12), which have become such a feature of modern Scandinavian housing schemes, can (as mentioned in the section on planning), be adapted to almost every type of requirement, provided the house is planned so that the dimensions are multiples of the sectional widths. The construction of these sections at the factory is a great saving in cost, as no waste timber is carted to the site. Each section is about 5 ft. in width, and for a two-storey house consists of a slab of wall, complete with window or door, extending from the ground cill to the roof plate, or in the case of a gable end to the apex of the gable. At the angles and also at all joints between the sections, the outer sheeting is omitted until the main walling is properly fixed, after which the outer planking and laths, supplied in cut lengths with the sections, are fitted together.

The standardisation of the wall sections (Fig. 12) does not necessitate a

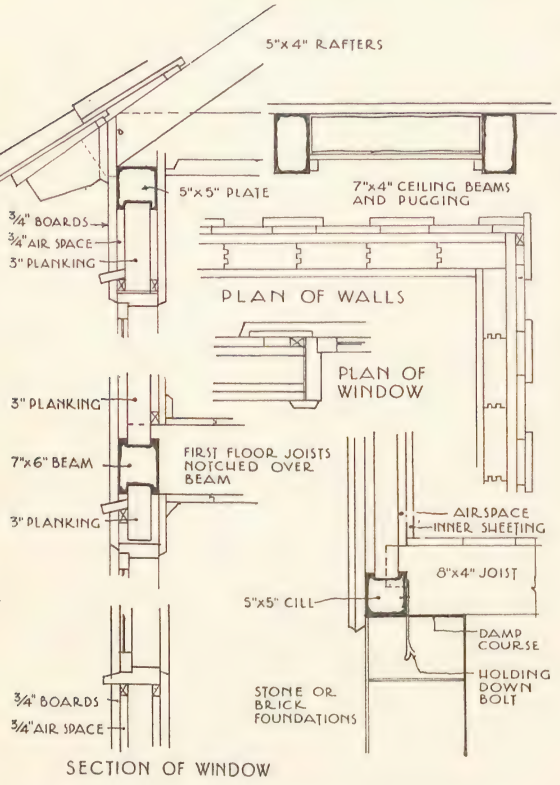


Fig. 13.—NORWEGIAN TIMBER CONSTRUCTION

standard plan, which in Swedish housing estates is variable to suit different requirements. The plans illustrated show two typical cottages which have been built in the suburbs of Stockholm from pre-fabricated sections. The external dimensions are similar and the cellars alike, but in one the ground floor is divided into a large living-room, hall, cloakroom, and a kitchen, with two double bedrooms and an attic over; while in the other the kitchen is smaller, with a dining-recess, and the first floor is divided into two single and one double bedrooms. The staircase and fittings are standard to the two types. Further modifications are possible by placing the porch at the end, and extra rooms can be added as required, all built up from the standard wall sections.

To erect the sections, a cill is first laid all round the building upon a proper damp-course, and secured with bolts to the foundation wall. These cills are usually about 8 in. by 3 in., laid with the 3 in. vertical, so that the ground-floor joist, as well as the walls, obtains a bearing. The cill of the pre-fabricated section, usually 5 in. by 4 in., is laid on this, and the whole section raised into position and held in place with props until the next section is in place. As soon as the outer walls are in position the inner partitions are fixed and the first-floor joists laid. These latter have already been cut to lengths at the factory, and slots left in the wall planking to receive them. They are given an extra security by having anchor irons screwed to the under side, which are bent over and screwed to the inner side of the wall planking. When the walls are thus finally secured, the brick or concrete flue or flues are built and the roof timbers erected in the normal manner. Floorboarding is usually $1\frac{1}{4}$ in., grooved

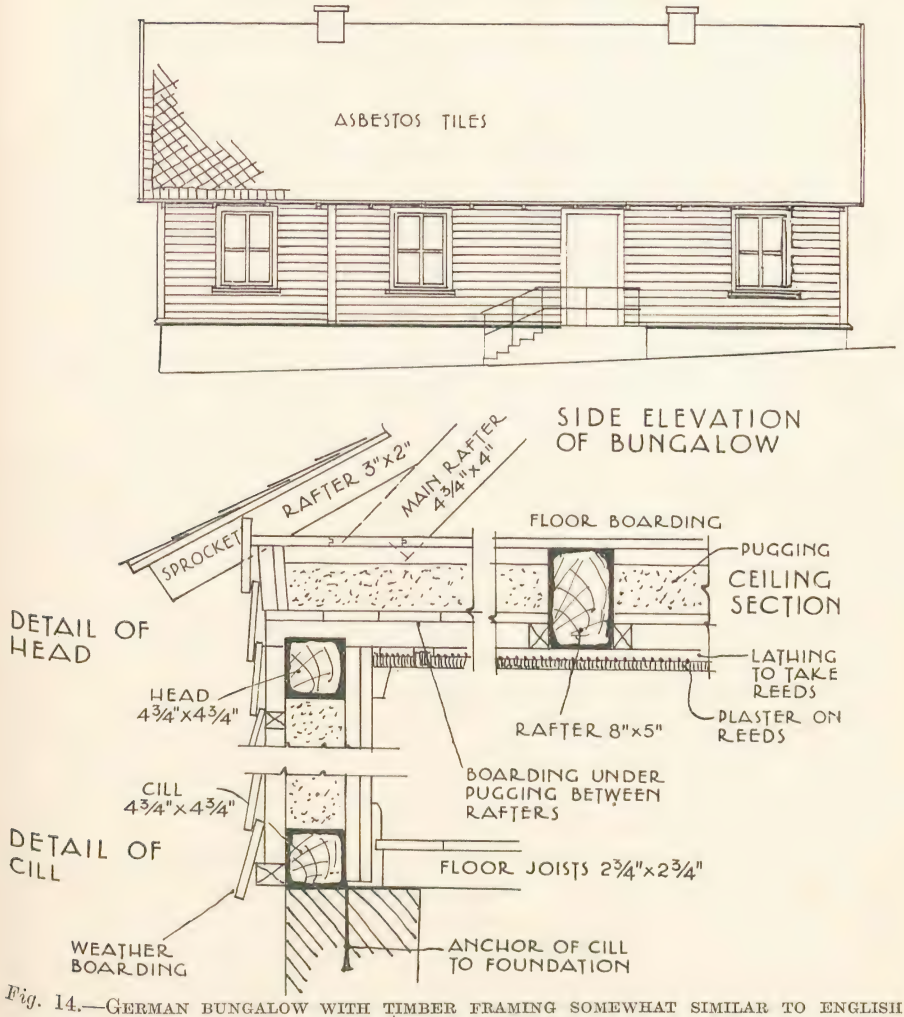


Fig. 14.—GERMAN BUNGALOW WITH TIMBER FRAMING SOMEWHAT SIMILAR TO ENGLISH HALF-TIMBER CONSTRUCTION

and tongued, and a similar boarding is put to both the outer and inner sides of the roof rafters. The roof is battened and counter-battened, if steeply pitched, and then covered with tiles.

Insulating paper is frequently laid between the floor joists and turned up at the sides as an extra precaution against cold, and under the ground floor the cellar ceiling is often double boarded with an air space between the two layers of $\frac{3}{4}$-in. boards. A typical specification is as follows :—

Specification

The wood to be of the best quality, dry and properly seasoned. All to be planed with the exception of the roofing laths and outside of external

boarding. The lower cills to be of 9 in. by 3 in., with upper cills 4 in. by 4½ in., rebated for wall planking as shown on detail.

The joists to be cut to exact sizes and ready for building in. For spans under 15 ft. to be 9 in. by 3 in., and for wider spans, unless otherwise specified, 9 in. by 4 in. Joists under internal partitions to be double. The external walls to be built of 3-in. grooved and tongued planks ready for building as wall. The internal face of this framing is to be covered with a layer of waterproofed paper and ¾-in. matched boarding fixed to 1½-in. by 2-in. battens. The outer side of the framework is to be covered with asphalte waterproofed paper, and this is to be covered with 1-in. vertical rebated boarding on the outside, the exposed face of this boarding to be unplaned. The joists are to be covered with 1¾-in. by 2-in. rebated laths as shown on detail. The gables are composed of 1-in. planed and rebated boarding on 2-in. by 3-in. framing.

Roof plates to be 6 in. by 3 in., and rafters of 3 in. by 6 in. or 3 in. by 7 in. The plates to be bored for bolting to frame.

Floorboards to be 1¼-in. by 4-in. or 1¼-in. by 5½-in. pine of best quality. Bathroom, w.c., attic, and under-boarding to be 1-in. planed and rebated boarding.

The cellar roof to be 1-in. rebated boarding except in washhouse, garage, and w.c. These ceilings should be plastered.

The under-boarding of ground floor is of ¾-in. boarding fastened to the lower cill with 1-in. by 1¼-in. battens spiked on.

The partition walls are to be of 2-in. grooved and tongued planks covered with waterproofed paper, fixed to battens, and ¾-in. grooved and tongued boards.

Norwegian Timber Construction

Norwegian timber construction (Fig. 13) varies slightly in that the centre of the wall is composed of 9-in. by 3-in. planking with an air space on both sides. The external boarding is ¾ in., laid on battens, with full-width cover boards in place of the Swedish laths at joints, and a similar arrangement occurs inside, where a species of wall board is fixed to the inner battens. The framework is carried on 5-in. by 5-in. cills fixed to foundations with a holding-down iron. These cills are grooved at the top to take the vertical planking, and the ground-floor joists are also notched over them. Unlike the Swedish system, the first floor has a 7-in. by 6-in. beam all round, double grooved to take head of ground-floor and foot of first-floor planking, and the first-floor joists are also notched over this beam where they occur. A plate at head similar to that on the foundation is steadied by 7-in. by 4-in. ceiling joists and carries the 5-in. by 4-in. rafters. The ceiling beams are often boarded and pugged to ensure better insulation from the roof, which is battened but not boarded.

MODERN TIMBER CONSTRUCTION

PART II.—FRAMED-AND-BRACED CONSTRUCTION—SELECTION OF TIMBER—ROOFS AND ROOFING

BUILDINGS constructed of timber framing are not usually of more than two or three storeys in height, although there is no reason for this limit, provided proper bracing and cross-bracing is employed, with suitable size timbers. But the average and most economical scantlings used to-day range from 4 in. by 2 in. to 4 in. by 4 in. for studding and cills, with floor and ceiling joists up to 9 in. by 2 in., and the following descriptions of constructive methods apply to a two-storey house raised on a basement wall, with a pitch roof, which is the most common type to be met with.

Such buildings may be erected by one of three methods, which will be referred to as methods A, B, and C.

Method A (Fig. 17).—In method A the cill plate, 4 in. by 3 in., is bolted to the basement wall and halved at the angles, and on this are set up the angle-posts of 4-in. by 4-in. scantlings running the full height of the walls. Into the angle-posts, in positions to take the first-floor joists, are framed horizontal 4-in. by 3-in. timbers known as half-way plates. To avoid weakening the angle-posts the half-way plates running parallel to the first-floor joists are framed into them at a higher level, and the end joist placed close up against them. The main angle posts are strutted to the ground-floor cill by diagonal braces. Similar bracing is employed both above and below the half-way beam and under the head. The main 4-in. by 2-in. studding is cut to fit in between ground cill and half-way plate and half-way plate and roof plate. The roof plate, usually 4 in. by 3 in. or 4 in. by 4 in., should be able, with the aid of the ceiling joists, to tie in the upper floor. Roof rafters are notched over the head, and to minimise thrust the ceiling joists are spiked to them.

Rough floorboarding, laid over the ceiling joists to form a loft, and also over ground and first floors, acts as a further tie, the whole structure being finally secured with diagonal boarding over the outside. Where an inner partition occurs which takes weight from the upper floor or roof, it is carried on a floor binder with fillets nailed on to carry ground-floor joists, unless there is a direct bearing on to a wall, when an ordinary 4-in. by 3-in. plate is used. Grooved and tongued cross-flooring is laid as a finished floor over the rough boarding, and weather-board or side lap

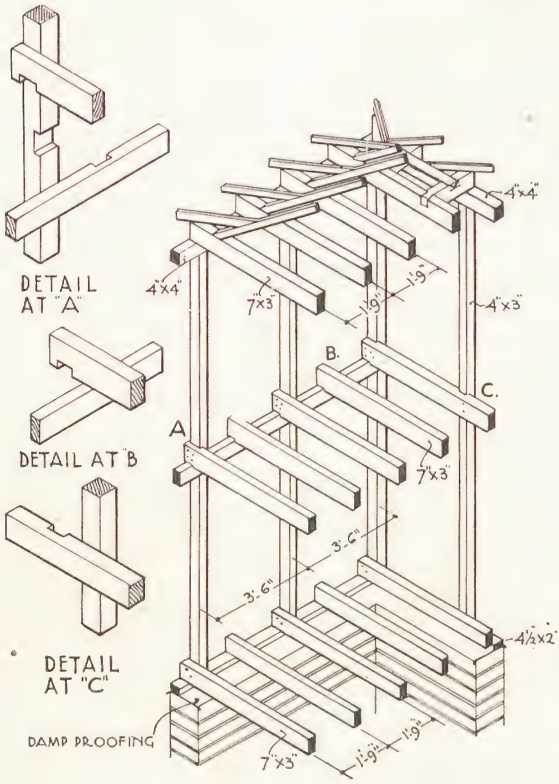


Fig. 15.—LIGHT TIMBER FRAMING FOR GROUND AND FIRST FLOORS

nailed on to the external diagonal boards, with or without an asphalte paper between, completes the weatherproofing of the building.

The inner face of the studding may be plastered in the ordinary way, as also may the ceilings, but it is a better scheme in a timber building to keep the plasterers out altogether, and to cover both walls and ceilings with some brand of wall or plaster boarding. The work is quickly done by the carpenters and joiners on the job, without introducing another trade, and the result is a much drier house ready at once for occupation.

Method B (Fig. 16).—Method B employs the most complicated type of construction. Here the ground cill is approximately 6 in. by 3 in. laid flat, and on the outer side of this is placed a timber the same depth as the ground-floor joists, approximately 9 in. by 2 in., all round the outer walls. The diagonal rough flooring is carried right over to the outer face, and on this is set the 4-in. by 3-in. plate to take the feet of the wall studs. These studs are held in below the first-floor level with a double 4-in. by 2-in. plate halved at the angles, and are further stiffened by diagonal ties. The angle posts are built up of 4-in. by 2-in. timbers (usually three spiked together). There are various other methods of arranging these angle posts, as shown in the small details.

On top of the double head-plate another vertical header is carried all round and the process of the ground floor repeated over again. The ceiling joists, which together with the rafters rest on another double plate, are stiffened with similar diagonal boarding to the floors, and have herringbone strutting at intervals. Internal partitions are carried on girders where they occur over voids, but it should be noted that the diagonal rough boarding is carried over these before laying the plate at the foot

of the partition itself. All internal partitions are braced at intervals, and double lintels of 4 in. by 2 in., with diagonal braces to throw the weight to either side, are placed over all door and window openings.

The finishings, both externally and internally, are similar to those employed in method A.

Method C (Fig. 15).—In method C, solid 4-in. by 4-in. angle posts run the full height of the building, tied in at ground-floor cill and head. Between the angles the studding also runs the full height. These studs may be 4-in. by 2-in. sections as in the other methods, set 16 in. apart, or stouter, as in some German examples spaced as wide as 3 ft. 6 in. apart, as shown in the sketch, but in these cases strengthened against lateral movement by bracing (which has been omitted for clearness). On to these uprights are halved horizontal plates to take the first-floor joists, and where the wall runs parallel with the joists, these themselves are notched round the studs for strength. A further tie is obtained by notching and spiking the ends of the joists to every alternate vertical stud. In the German example shown the timbers are large, both ceiling and floor joists being of 7-in. by 3-in. timbers, the former spiked down on to the 4-in. by 4-in. head. It should be noticed that in this instance there is no wall plate above the ceiling joists to take the rafters, which are tenoned into the ceiling joists themselves, having a sprocket piece to form the eaves. Another constructional point, employed to receive a

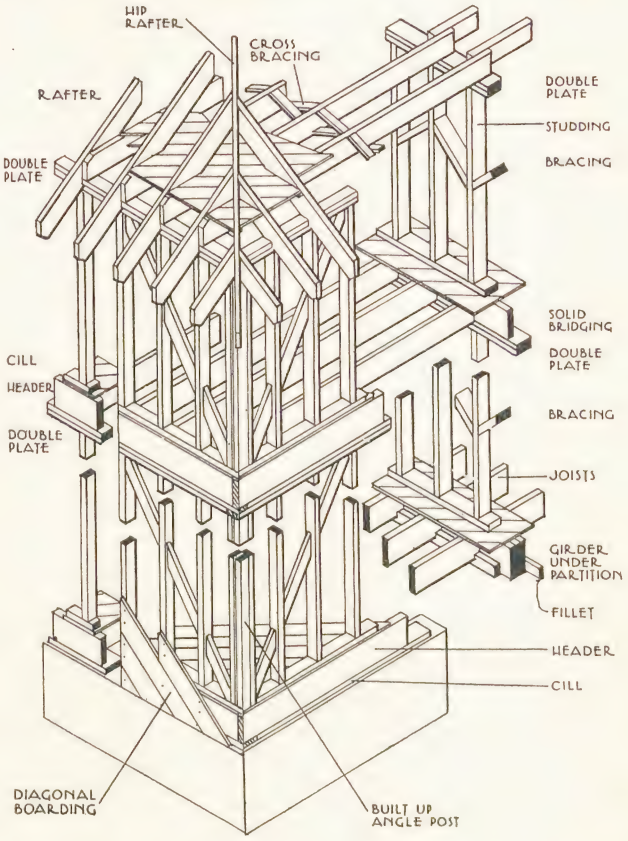


Fig. 16.—CONSTRUCTION OF BUILT-UP ANGLE POST AND TIE BEAMS

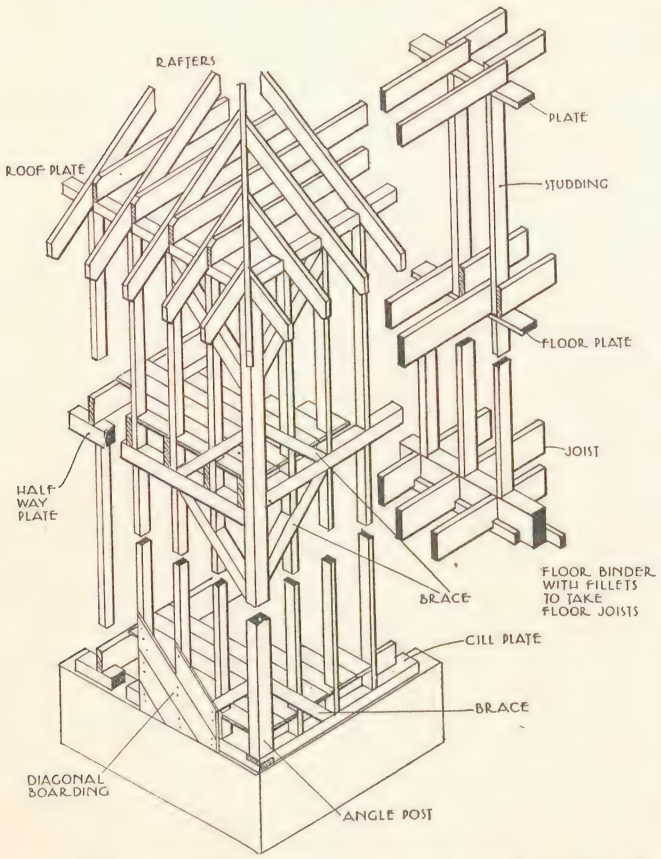


Fig. 17.—CONSTRUCTION WITH SINGLE ANGLE POST AND STUDS AT 16-IN. CENTRES

further stiffening of the wall framing where the ceiling rafters run parallel to the walls, is the short length of rafter above the first floor, spiked to the head and dovetail unioned at right angles into the end rafter. The 4½-in. by 2-in. cill on the brick basement wall carries the ground-floor joists as well as the uprights, and is laid on a damp-proof course in the usual way (Fig. 18).

The outside of this type of building can be boarded with horizontal and diagonal boarding as already described, and finished internally with wall boarding.

In all the three examples, openings required, such as spaces for chimneys, etc. (Fig. 19), must be trimmed and the joists doubled all around such openings, and this must also be done to joists under partitions running parallel to them. Through bracing must also be provided by one or more rows of bridging, either solid or herring-bone. The diagonal sub-floors already referred to are an integral part of the structure, and must have the rebated boards securely nailed in place.

Where the walls are 20 ft. in length it will be necessary to erect them in sections, and for these, building method B is the best, as the sections can be framed together on the ground and raised into position.

Best Woods for Timber Buildings

Some of the best woods for these framed wooden buildings are Empire timbers, and the following have been used with good results :—

For upper-floor joists, roofs, and studding :—

Ukay No. 1 Merchantable Douglas Fir or Western Hemlock, planed all round to finish $\frac{1}{4}$ in. less in each direction than nominal size.

For plates, ground-floor joists, sub-flooring, beams, and posts :—

Similar Douglas Fir, but in damp situations substitute Merchantable Western Red Cedar.

Flooring :—

No. 2 Clear and Better Edge Grain, Kiln-dried Douglas Fir or Western Hemlock, if the floors are to be left exposed and polished. But if carpets or linoleum are laid, this grade wood may be dispensed with, and No. 2 Clear and Better Random Grain Kiln-dried can be substituted at less cost.

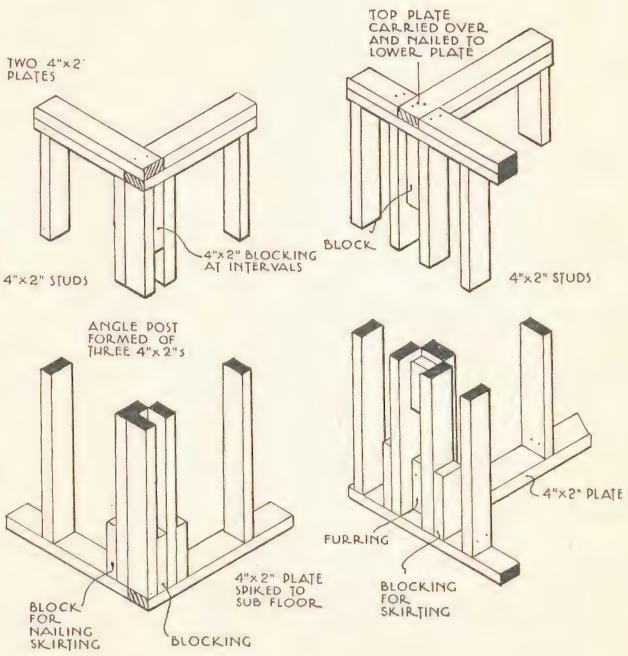


Fig. 18.—JOINT OF CROSS AND EXTERNAL WALLS

The eaves boards and exterior finish :—

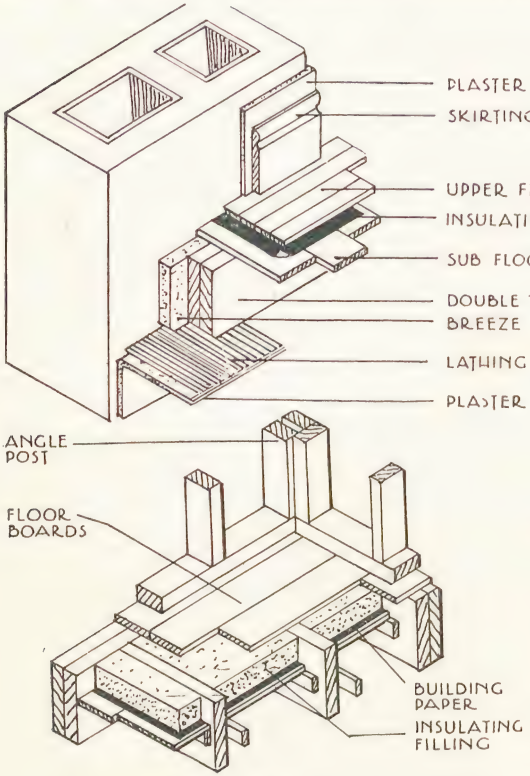
Ukay Select Merchantable or No. 2 Clear and Better Western Red Cedar.

The foregoing terms have been standardised by The Canadian Lumber Association, and the timber merchant knows exactly what to supply when they are specified.

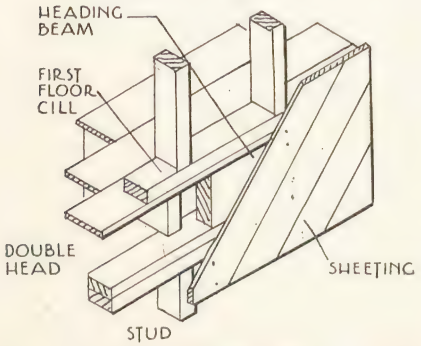
External Sheathing

As a general rule sheathings are laid horizontally in Canada and America, and vertically in Scandinavia and most of Northern Europe.

The term weather-boarding used in this country generally denotes 1-in. or $\frac{3}{4}$-in. planed or sawn boards laid over one another, but Canadian practice can now supply varieties of timber sheathing several of which are more waterproof than ordinary boarding. These are known as (Fig. 20) "Bevel Siding," "Bungalow Siding," "Rustic Siding," and "Drop Siding." The first two are simple types of familiar feather-edge boarding, "Bevel Siding" diminishing from $\frac{1}{2}$ in. to $\frac{5}{32}$ in. in thickness and



DETAIL OF ANGLE SHEWING FLOOR FILLING INSULATING MATERIAL LAID ON BUILDING PAPER. THE SUB FLOOR SHEWN IS CARRIED UNDER CILLS OF FIRST FLOOR. STUDDING COUNTER FLOOR (NOT SHEWN) LAID UP TO INSIDE OF CILLS



DETAIL SHEWING CONSTRUCTION AT FIRST FLOOR WITH DOUBLE HEAD TO CARRY JOISTS AND HEADING TIE. OUTER DIAGONAL SHEETING BOARDS SHEWN.

Fig. 19.—VARIOUS DETAILS OF HOLLOW TIMBER-FRAMED BUILDINGS

obtainable in from 4-in. to 8-in.-wide planks. "Bungalow Siding" diminishes from $\frac{3}{4}$ in. to $\frac{3}{16}$ in., and is obtainable in 8-in., 10-in., and 12-in. widths. "Rustic Siding" is rebated at each end and bevelled on the outside, so that when put together, horizontal V-joints show between the planks. The planks are approximately $\frac{3}{4}$ in. thick and 6 in. wide.

"Drop Siding" is rebated at the bottom edge and hollowed to a curve along the top edge to half the thickness of the plank, so that it fits in behind the rebate of the plank above. Another more elaborate shape is grooved on the bottom edge, and the upper edge is rebated as well as splayed. Both types are $\frac{3}{4}$ in. thick and about 6 in. wide.

The dimensions of the rebates and splays have been carefully standardised, therefore the fitting together of all Canadian planking should be easy if the wood is obtained from the best merchants.

Vertical Boarding in Northern Europe

The vertical boarding used in Northern Europe (Fig. 21) is usually butt-jointed and covered with a strip, either square-edged, splayed, or rounded. Sometimes these strips are rebated over a groove at the

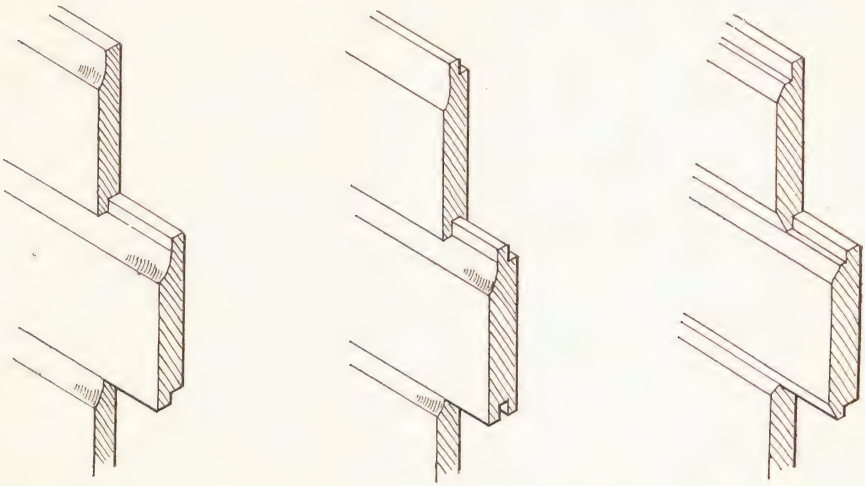


Fig. 20.—DIFFERENT TYPES OF REBATED SIDING IN 6-IN. BY ¾-IN. BOARDING

edges of the boarding, for extra protection, and certain special examples have a groove down the whole length into which tongued boards are fitted. Where the vertical boards overhang the basement wall of the building they are splayed up to form a drip.

Heat Insulation

Walls so constructed have been tested for heat insulation with the following results :—

" The measure of heat transmission is the coefficient of heat transmission which is the amount of heat in British Thermal Units radiated, absorbed, or conducted by a surface of 1-in. thickness of a material per square foot of that material per hour per degree of difference of temperature inside and outside."

On this formula such a timber wall as described transmits ·189, as compared with a

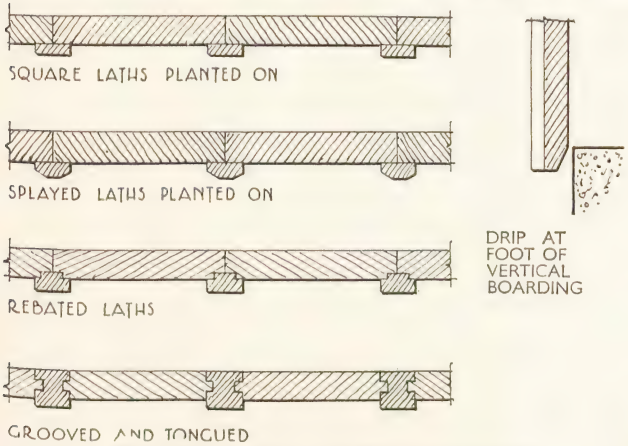


Fig. 21.—LATHS TO VERTICAL BOARDING

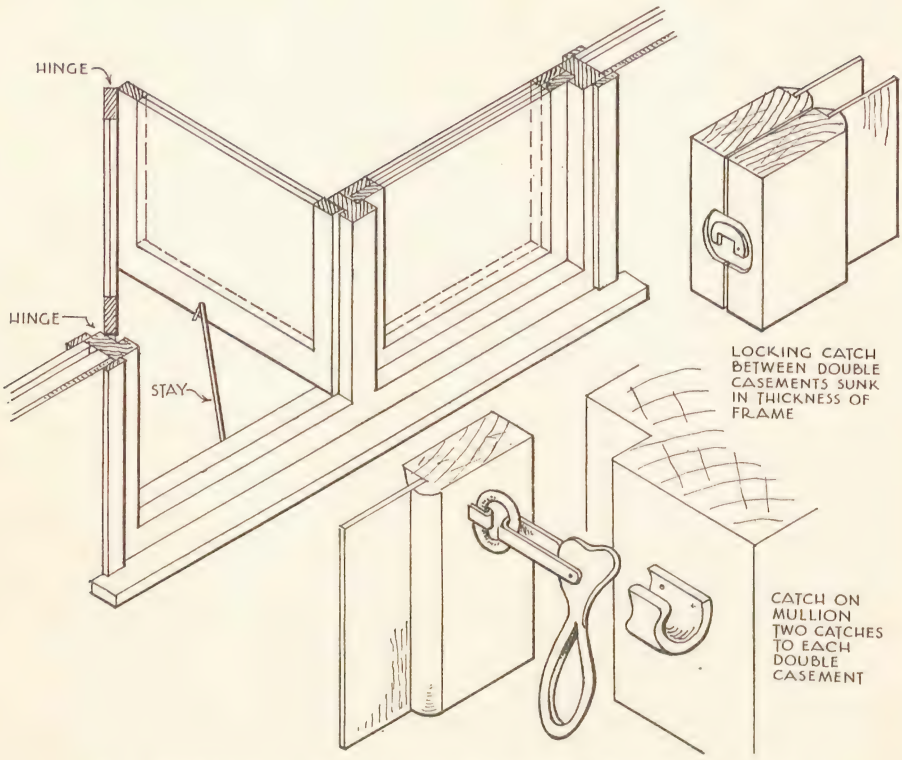


Fig. 22.—SWEDISH TYPE OF DOUBLE WINDOW IN WOODEN HOUSES

9-in. plastered brick wall, which transmits ·213. An even higher insulation is claimed for the solid timber walls from tests made in Scandinavia.

Insulation of Solid-framed Wood Building

An experimental test of the heat losses in a small wooden house of the types described made in Sweden gave the following results :—

Through the walls, 53 per cent.
" " ceiling over bedrooms under roof, 17 per cent.
" " ground floor over cellar, 13·5 per cent.
" " windows, 14 per cent.
" " doors, 2·5 per cent.

The walls in this were lined internally with " Tretex " laid on the main planking, with an air insulation space between the planks and outer boarding.

The slight loss through the windows was probably due to the special type of double windows employed in nearly all Scandinavian wooden

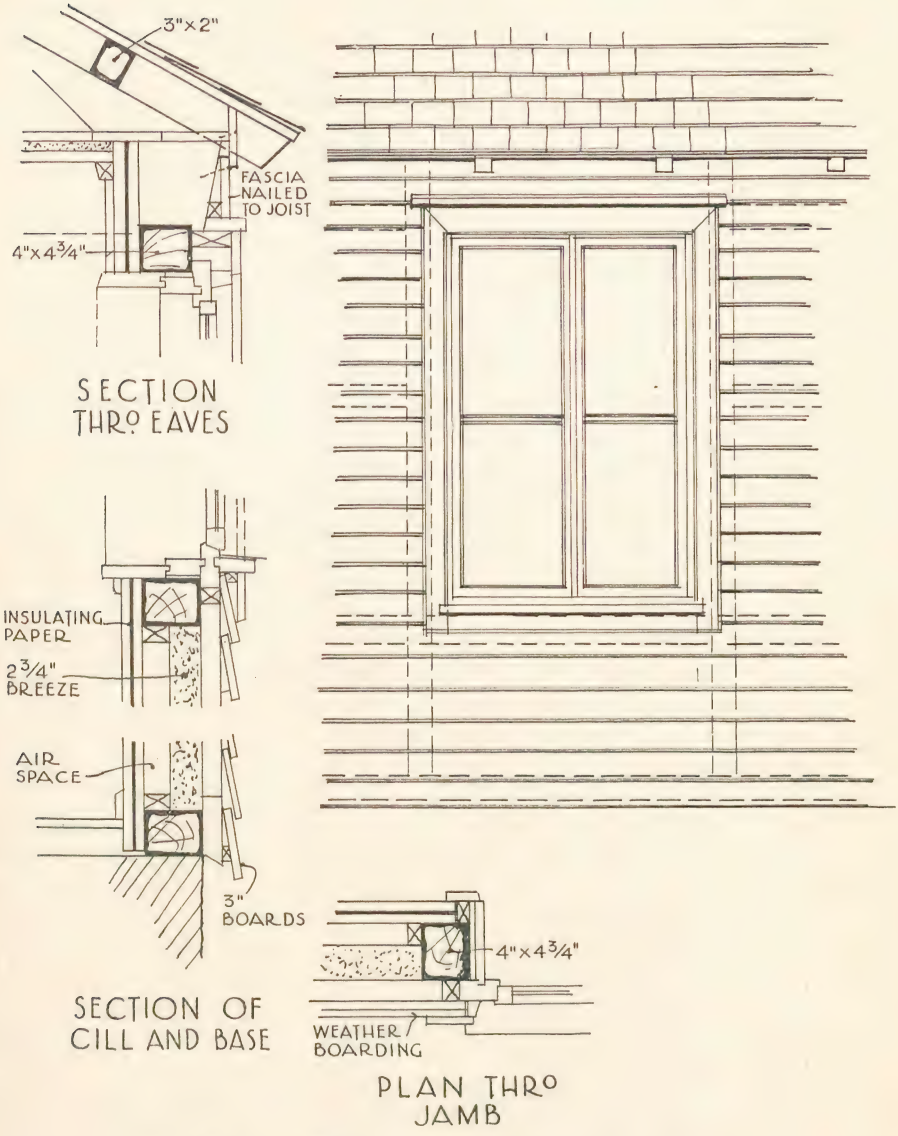


Fig. 23.—WINDOW IN WEATHER-BOARDED WALL

houses (Fig. 22). This consists of a double sash fastened together with a clip on one side and hinged at the other. The outside sash only is hinged to the solid window frame, so that the double window opens and shuts like an ordinary casement. When required, the clips can be released and the two sashes spread out and fixed in the opening in a

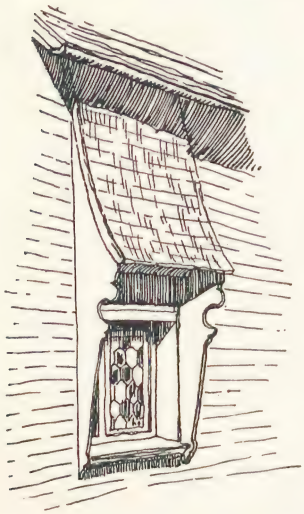


Fig. 24.—ANOTHER EFFECTIVE TYPE OF WINDOW

triangular form, thus giving ventilation through the top and bottom and preventing draught if the wind is blowing directly towards that side of the house.

Whatever type of window is employed, the best and most weather-tight method (Fig. 23) for finishing the exterior is to fix an architrave all round to cover the ends of the weather-boarding, whether vertical or horizontal. In the latter case this makes a good joint under the cill and prevents the drips blowing back. Some sort of weather-board at the head is also a safeguard, and should project sufficiently to throw the rain clear of the window.

Another very effective type of window is used in Switzerland (Fig. 24). This consists of two cut brackets projecting at right angles to the wall boarding, the upper part of each being shaped back to the wall and covered with either boarding or wood shingles. In exposed situations this window framing is a great protection, the pent roof projecting sufficiently to throw either snow or rain clear of the wall.

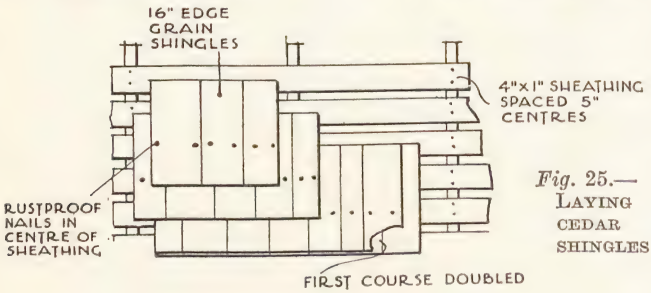


Fig. 25.—LAYING CEDAR SHINGLES

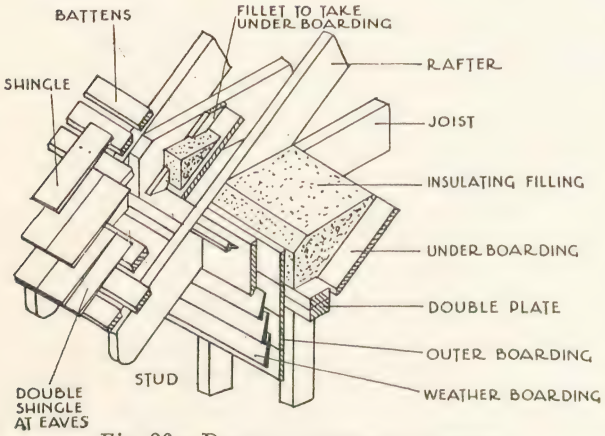


Fig. 26.—DETAIL OF SHINGLE ROOFING

Wood Roofing

One of the best materials for pitched roofs of not less than 1 in 3 rise, or 30°, is probably cedar shingles (Figs. 25 and 26). The roof should not be close boarded or fitted, as the shingles require ventilation, but laid with 3-in. by 1-in. or

4-in. by 1-in. battens spaced at 5-in. centres. British Columbia shingles are rift-sawn from Western red cedar, which prevents the tendency to split, warp, or curl, and any shingle not so cut is likely to give trouble. The shingles are cut thicker at one end than the other, and Canadian shingles are graded as follows :—

5X.—Length 16 in., thickness 5/2, that is, 5 butts measure 2 in. in thickness. They are packed in bundles, and can be had in mixed widths from 3 in. to 14 in., and when laying should not have an exposed surface of more than 5 in. Four bundles should cover 1 square of roofing.

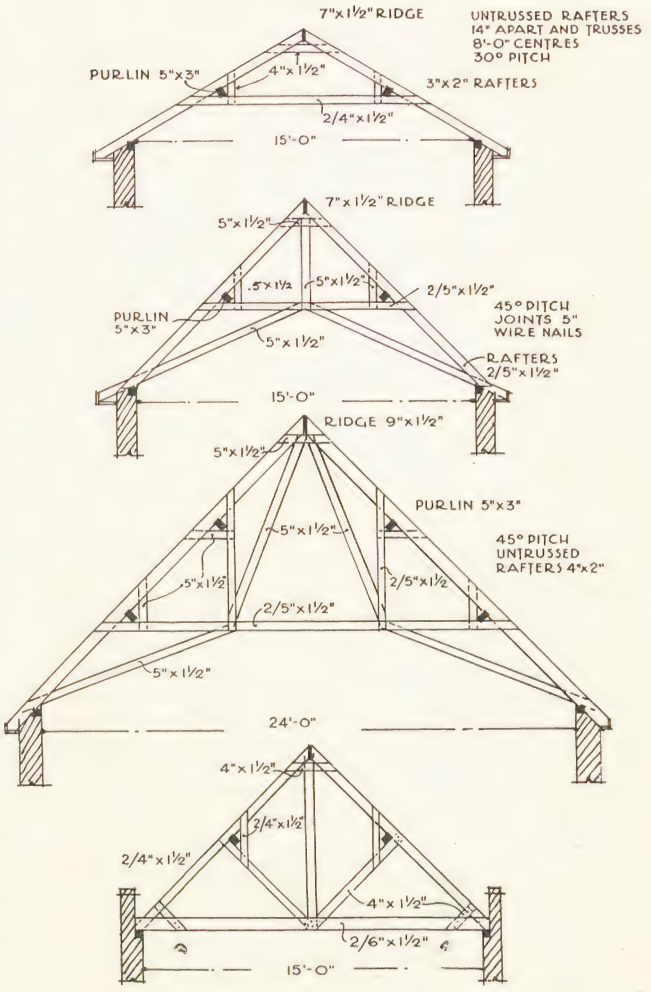


Fig. 27.—VARIOUS ROOFS OF LIGHT SCANTLINGS

Perfecteon—Length 18 in., thickness $5/2\frac{1}{4}$. These are packed in bundles and obtainable in similar mixed widths, and the exposed surface should not be more than $5\frac{1}{2}$ in.

A similar number of bundles will cover 1 square as in 5X's, and they should be used where a slightly better job is required.

Royal—Length 24 in., thickness 4/2. They are supplied in mixed widths between 4 in., and 14 in., and should have an exposed surface of not more than $7\frac{1}{2}$ in. These shingles are used where the best type of roofing is required.

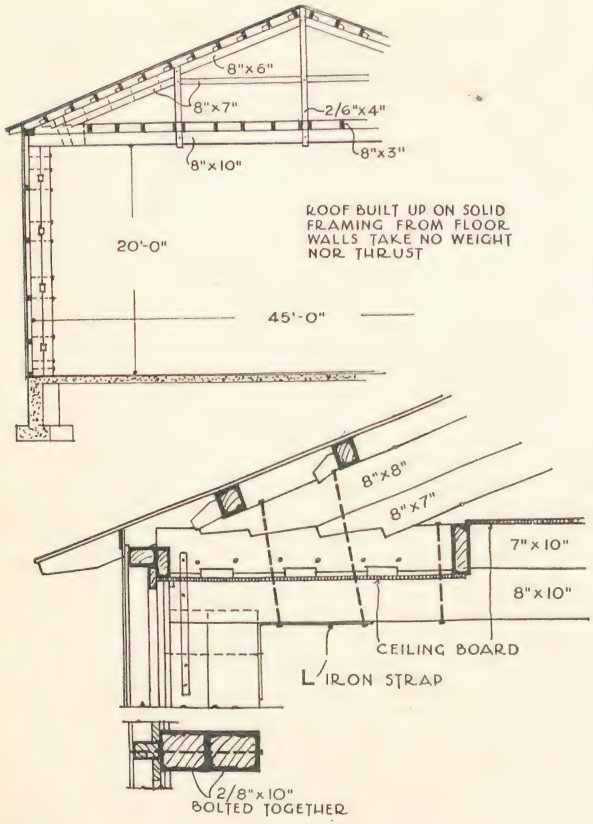


Fig. 28.—DETAIL OF CONNECTION AT EAVES BETWEEN POST AND TRUSSES

Nailing

On no account should common galvanised iron nails or wire nails be used. The life of a common wire nail is from five to seven years, and a properly constructed shingle roof should last forty. The use of a cheap nail is therefore false economy if the roof has to be stripped and re-nailed during its life. The best nails are copper, or if these cannot be had, hot spelter zinc-coated nails are the best substitute, and the lengths should be as follows:—

	Nails	*Gauge*
5X shingles ..	1⅛-in.	15
Perfecteons ..	1¼-in.	14
Royals ..	1½-in.	13

Weight

In calculating the strength required for the rafters, the following weights may be used for Canadian cedar shingles :—

5X..	144 lb. per square
Perfecteons	158 „ „ „
Royals	192 „ „ „

It will be seen from this that a considerable saving may be made in the sizes of roof joists when these weights are compared with those of slates or tiles.

Laying

Before beginning to lay the roofing, set aside enough wide shingles for fitting the valleys, and enough 5 in. or 6 in. wide for hips and ridges. These latter are trimmed to fit after laying by cutting off the surplus from the top edges, the bottom edges being laid in line.

Lead flashing in the valleys should be 5-lb. lead approximately 15 in. wide, and the valley shingles nailed near the hips to avoid piercing it. Begin laying at the eaves in the usual manner of tiling, and lay the first course double. Break joints 1½ in. side lap and space the shingles so that no joints are exactly above each other; care must also be taken to keep the courses straight. The best way of doing this is by means of a chalk line.

Special care should be taken to see that the fixer spaces the shingles from ⅛ in. to ¼ in. apart to allow for expansion. Each shingle requires to be nailed with two nails, spaced approximately ¾ in. from the sides of the shingle and 1 in. above the exposure line, and the nails should be driven until their heads are just flush with the surface of the shingle: harder driving may split the cedar, or at least bruise it. By this method each shingle is secured in four places: by the two nails driven into itself, and by the two driven through it from the shingle next above it.

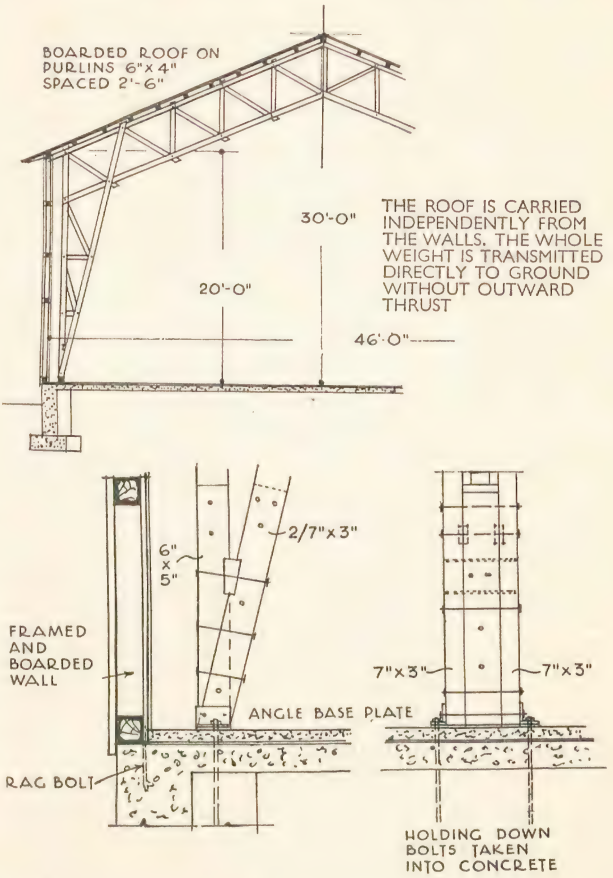


Fig. 29.—FRONT, SIDE, AND HALF ELEVATION OF TRUSS

Lastly, before beginning to lay, it is a good plan to give the shingles a good soaking with water. Cedar shingles do not require paint or stain to preserve them, as the wood contains a natural oil which, when left untreated, weathers to a silver-grey.

Roofs. Trusses

Modern timber construction is capable of utilising small scantling timbers to build up quite considerable roof spans (Fig. 27). The principle

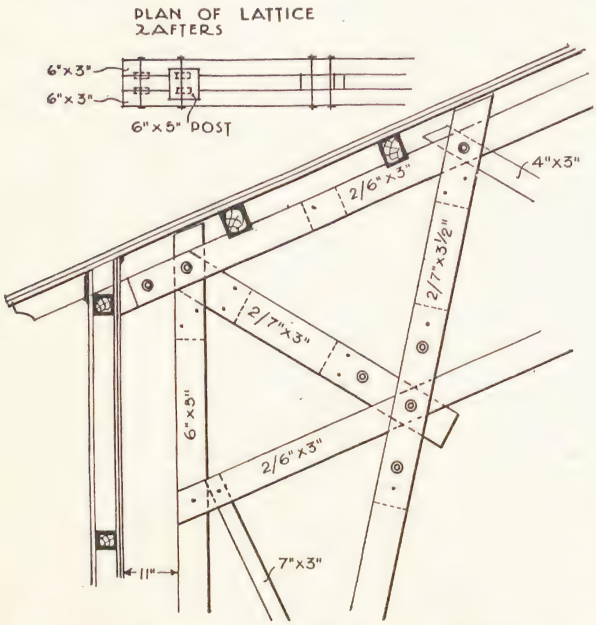


Fig. 30.—DETAIL AT EAVES, SHOWING CONNECTION AT HEAD OF POST

of the well-known Belfast roof truss can be employed for other types of roofs. A low-pitch roof up to 15-ft. span can be built up of 3-in. by 2-in. rafters, held with a double collar of 4 in. by 1½ in. below the purlins, and another 4 in. by 1½ in. below the ridge.

A steeper span requiring greater head room, suitable for a small hall, is constructed of two 5-in. by 1½-in. rafters bolted together, with 5-in. by 1½-in. ties below the purlins and straining pieces, also of 5 in. by 1½ in. from the wall plates to the collar. A rather heavier tie-beam and slightly different construction can be used for a flat ceiling.

Another roof, of 24-ft. span, is shown, also built up of 5-in. by 1½-in. timbers. These trusses are all simple to construct of the ordinary timbers used on the job, and are considerably cheaper than steel trusses, and as they exert no more thrust than an ordinary truss can be suitably framed up on a wooden structure as well as on brick or stone walling.

Still greater spans can be covered, and in Germany wide roof openings are spanned in timber by methods which relieve the walls of the weight, carrying it direct to the foundations, and thus allowing the walls to act merely as weather screens.

Example No. 1

The first example (Fig. 28) is of a roof of 45-ft. span with the main trusses supported from the ground on two 10-in. by 8-in. baulks, bolted and tongued together. These support a double tie-beam, composed of one 10 in. by 8 in. and one 10 in. by 7 in., extending from upright to upright, having iron straps at the joints as well as being tenoned to the support. On the upper tie-beam is built up the roof truss of 8-in. by 7-in. and 8-in. by 6-in. timbers, secured with 6-in. by 4-in. straps on either side, bolted down to the lower member of the tie. The final main rafters which carry the purlins are 8 in. by 8 in. The whole of the roof

is thus carried independently of the walls, which can be built of any material, and have window or door openings of any size between the timber uprights.

Example No. 2

The other example is of a lighter structure for approximately similar span (Figs. 29 and 30). The weight is brought down to a small steel shoe by means of a braced upright member composed of 6-in. by 5-in. and 7-in. by 3-in. timbers. The braced truss is also composed almost wholly of light scantlings, between 6 in. by 5 in. and 7 in. by 3 in., framed and bolted together in the manner of a lattice girder. In this example, which gives a greater height having no horizontal tie-beam, the walls are also relieved of the weight and form merely a skin with only themselves to carry. Such types of large roofs can be designed for almost any reasonable span, and their variety is infinite.

Fig. 31.—ANGLE OF SWISS WOODEN BUILDING, SHOWING METHOD OF OVERSAILING WALL TIMBER TO CARRY ROOF

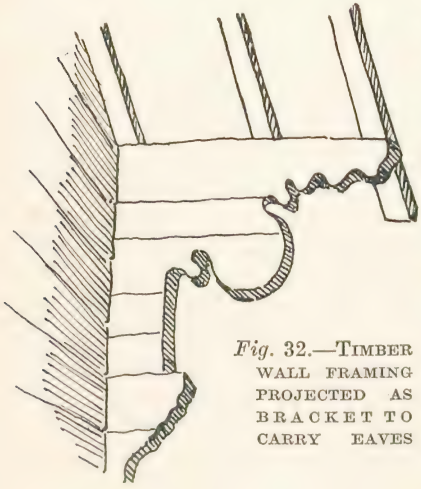


Fig. 32.—TIMBER WALL FRAMING PROJECTED AS BRACKET TO CARRY EAVES

Overhanging Eaves

Normally the projection of the eaves can be provided by the rafters with or without sprocket pieces, but where these are excessive, as is often

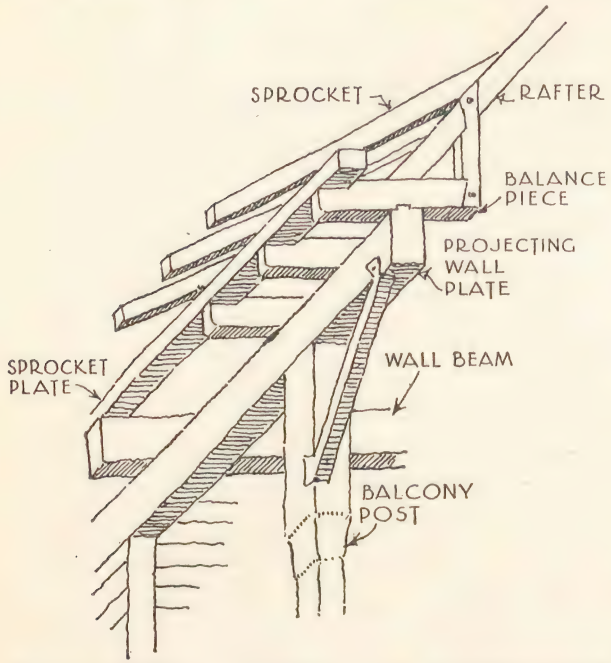


Fig. 33.—METHOD OF CARRYING WIDE PROJECTING EAVES OVER BALCONY

the case in Swiss houses (Fig. 31), the main timbers of the walls are contrived through and cantilevered out one upon the other to carry the projecting rafters. These structural cantilevers (Fig. 32) are often cut into ornamental shapes which add much to the appearance of the house.

Another ingenious method (Fig. 33), which is structurally sound, of roofing over a balcony, is to balance a short length of timber on the notched wall plate, the main rafter being tenoned into the centre ; from this balance piece an upright member is tenoned into the rafter on the inner side, and on the outer edge rests another plate called a sprocket plate, the sprocket pieces project over this and run back to the top of the main rafters.

Lamella Roofs

A timber structure which occupies a unique position in wooden roof design is the "Lamella roof." This consists of a number of small sections built up into a curved vault, on rather the same principle as a piece of expanded metal bent over between two supports. Very wide spans can be covered in this way, with either segmental or pointed Gothic roofs, and if the external walls are buttressed, or constructed of A-type steel struts, at intervals to take the thrust of the barrel vault, no tie-rods are needed for spans up to 165 ft. Such a roof is built up piece by piece on the site, and must be temporarily supported by light struts until the bolts and units are finally in position. Once the continuous cills are laid on the walls, and the end gable ribs fitted, the work of weaving in the pre-cut units proceeds quickly, and it is claimed that such a roof, for spans of 100 ft. and upwards, is from 5 to 2 per cent. cheaper than if it had been constructed with the usual steel trusses.

BRICKWORK

PART I.—TYPES OF BONDS

BRICKS have been used almost since the commencement of civilisation in the construction of buildings, bridges, aqueducts, and for many other uses.

The sizes of the bricks were varied, but were kept to a somewhat standardised shape, according to the national origin and the period at which they were made.

There is a standard specification for bricks in this country, and it is in accordance with this that the majority of the bricks are produced for use in the United Kingdom.

The method of erecting brickwork in the early times was very much alike to the present-day procedure, and the bonds used have been revealed to be exact replicas of English bond as used to-day, and many arrangements are of a combination of both English and Flemish bonds.

The majority of bricks used to-day are made of burnt clay, but the cause of economy has created quite a demand for sand-lime facings, to be used where light is required, in the place of white glazed, white Suffolks, or any other more expensive kind of burnt brick.

Clay varies in its quality and constituency, according to the district from which it is dug, and it is owing to this that we are able to have such a wide range of colours, textures, and general variety of bricks. (Full details of types of bricks will be found in Vol. III.)

BONDS

Brickwork in buildings usually consists of piers and walls, and these are designed to resist or carry the loads from floors and roofs superimposed upon them.

The walls and piers must be built so that all superimposed loads are equally distributed throughout their entire length. The arranging of the bricks is carried out in various kinds of bonds, and the most common of these are described below.

English Bond (see Fig. 1)

Consists of alternate courses or rows of *headers* (bricks laid the short side to the external side of the wall) and *stretchers* (bricks laid the long side to the external side of the wall).

This bond is considered to be the strongest of all arrangements, but it is not used where appearance is the main feature of the elevation to a building, owing to the repetition and closeness of the joints in the heading course.

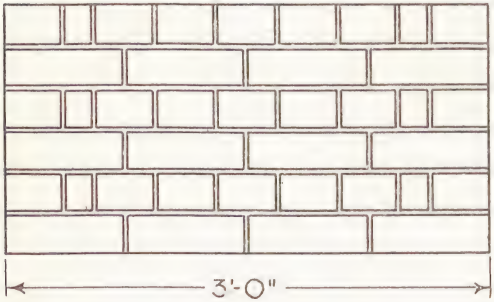


Fig. 1.—ELEVATION OF WALL BUILT IN ENGLISH BOND

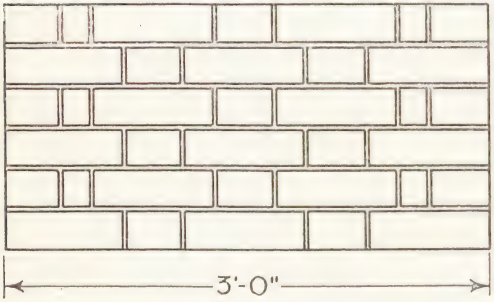


Fig. 2.—ELEVATION OF WALL BUILT IN FLEMISH BOND

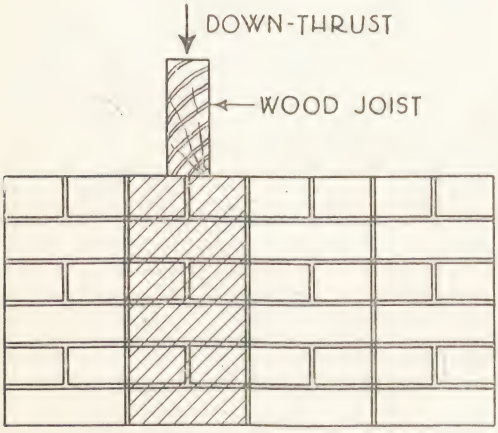


Fig. 3.—ELEVATION OF WALL WITH ALTERNATE COURSES OF HEADERS AND STRETCHERS

Flemish Bond (see Fig. 2)

Consists of alternate headers and stretchers in the same course. This is sometimes called double Flemish bond, implying that the Flemish arrangement is to appear both sides of the wall.

Single Flemish Bond (see Fig. 7)

This arrangement of bricks is said to combine the strength of English bond while preserving the elevation with Flemish bond. It is applicable to walls 1 ft. 1½ in. thick and over, and consists of Flemish bond on the external side of the wall and English bond on the inside.

A simple rule to remember is that on the external side on which the quoin header occurs, all the succeeding headers are of full length across the width of the wall, while on the opposite return, that is, the stretcher face of the quoin brick, all the headers in the course are snapped into 4½-in. bats, forming a 4½-in. facing skin.

Stretching Bond (see Fig. 8)

This bond is used for the construction of 4½-in. walls, chimneys, and hollow walls. The lap is 4½ in., and the centre of the stretcher should be kept in a vertical line with centre of the cross-joints above and below.

Heading Bond (see Fig. 9)

Bricks built in repeated courses of headers are used in

walls circular on plan, providing that the sweep is large enough, and in the footings of walls.

English Garden Wall Bond (see Fig. 10)

Consists of one course of headers to three or even more of stretchers. In the stretching course commencing with the quoin header, the closer is eliminated, and this forms a $4\frac{1}{2}$-in. bond with the stretching courses above and below.

Flemish Garden Wall Bond (see Fig. 11)

This is also known as Sussex bond, and is an adaptation of Flemish bond. It consists of three stretchers and one header alternately in the same course. It will be seen that the closer is done away with and a $6\frac{3}{4}$-in. bat is placed next to the quoin header. Also, that the centre of the header coincides with the centre of the stretchers above and below.

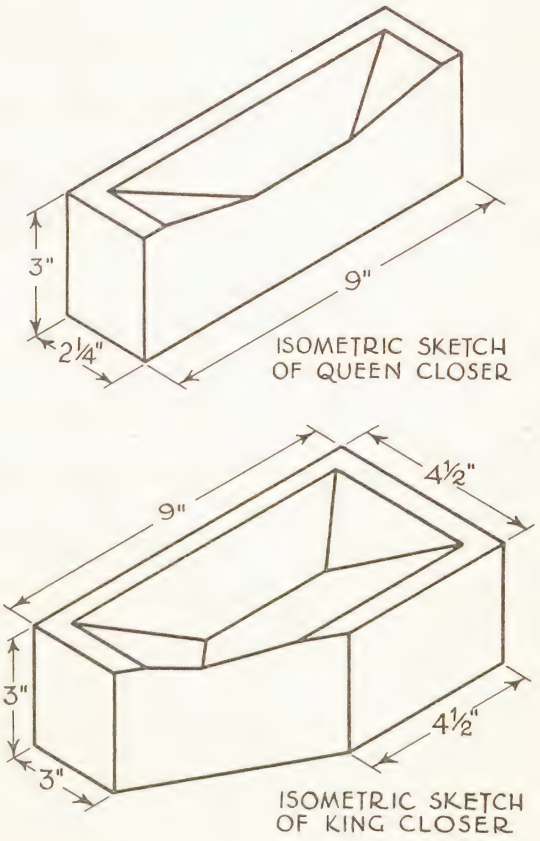


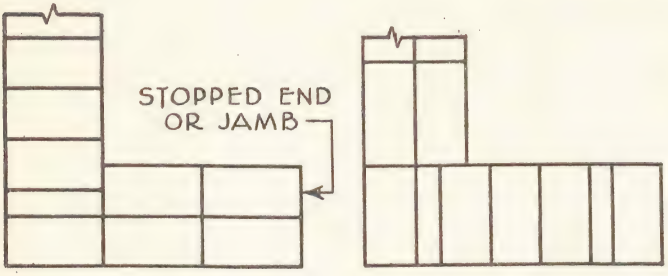
Fig. 4.—QUEEN CLOSER AND KING CLOSER

Both these garden wall bonds are very much used to-day in house construction, as it is possible to keep the back side of the wall more even or fair for plastering owing to the greater number of stretchers used than in either English or Flemish bond.

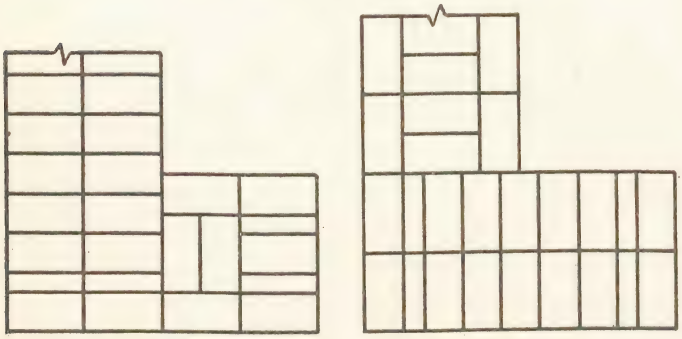
How the Weight is Distributed throughout the Length of the Wall

Fig. 3 shows a short wall built with alternate courses of headers and stretchers, but it will be seen that the weight placed upon the wall from the wood joist is only supported by the one-brick pier immediately beneath it.

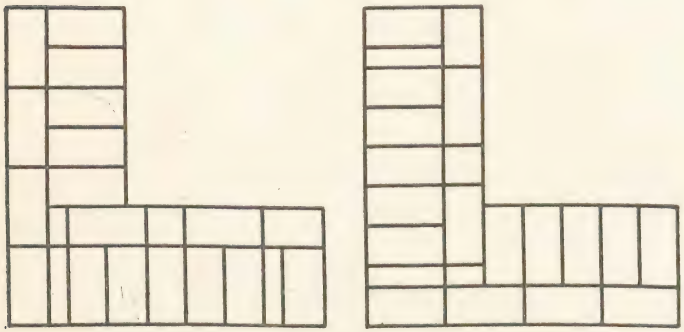
In order to distribute the weight throughout the length of the wall, the bricks must be arranged to make bond with one another longitudinally as well as across the width of the wall. Therefore, it is necessary to



ALTERNATE PLANS OF ENGLISH BOND TO AN ANGLE 9" WALL



ALTERNATE PLANS OF ENGLISH BOND TO AN ANGLE, 1'-6" WALL



ALTERNATE PLANS OF ENGLISH BOND TO AN ANGLE, 1'-1½" WALL

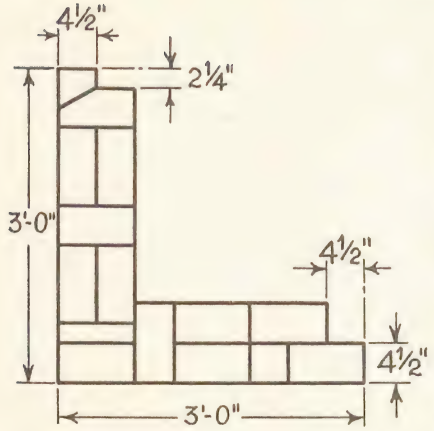
Fig. 5.—ALTERNATIVE ARRANGEMENTS FOR ENGLISH BOND

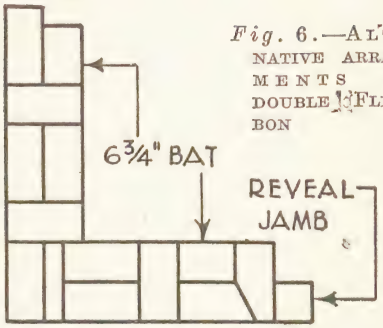
rearrange the bricks, causing the centre line of the header to coincide with the centre line of the stretcher above and below.

This method is adopted when setting out brickwork, as it gives definite equal lap either side of the stretcher. The *lap* is the distance from one vertical *cross-joint* or *perpend* in one course to the cross-joint in the course above or below. The above is also applicable to Flemish bond.

A Queen Closer

It will now be seen that, having rearranged all the bricks save the quoin or corner bricks, a space of 2¼ in. or a quarter of a stretcher is left between the quoin header and the next brick. This is filled in with a cut brick called a *Queen Closer* (see Fig. 4). For drawing purposes, this is made 2¼ in. wide by 9 in. long

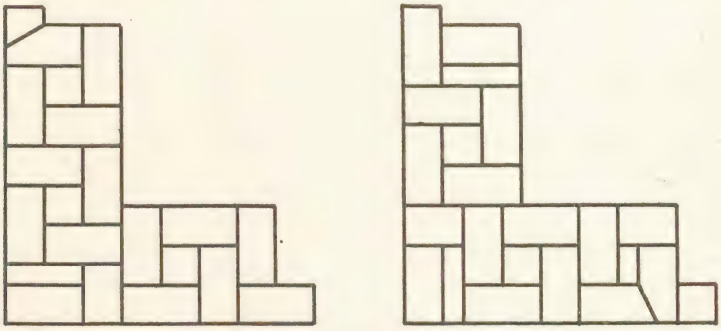




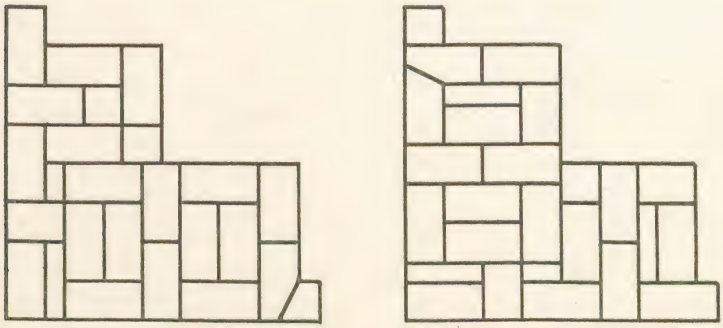
SPLAYED STRETCHER

Fig. 6.—ALTERNATIVE ARRANGEMENTS FOR DOUBLE FLEMISH BON

ALTERNATIVE PLANS OF DOUBLE FLEMISH BOND TO AN ANGLE 1.B.W. WITH 2¼" & 4½" REBATED JAMBS & 4½" REVEALS.



ALTERNATE PLANS OF DOUBLE FLEMISH BOND TO AN ANGLE 1½.B.W. WITH 2¼" & 4½" REBATED JAMBS & 4½" REVEALS.



ALTERNATE PLANS OF DOUBLE FLEMISH BOND TO AN ANGLE 2.B.W. WITH 2¼" & 4½" REBATED JAMBS & 4½" REVEALS.

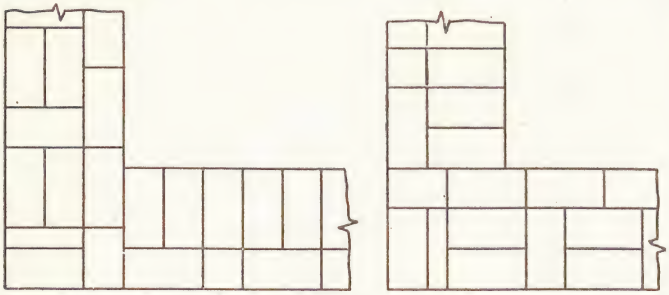


Fig. 7.—ALTERNATE COURSES OF SINGLE FLEMISH BOND TO AN ANGLE IN A 1-FT. 1½-IN. WALL

and 3 in. high, but it is usual, unless otherwise requested, to cut them from the stretcher side of a brick, placing two closers 4½ in. long to make up the required 9-in. width of wall.

Sectional Bond

In walls wider than 9 in., it is necessary to remember that all transverse joints must continue unbroken across the width of the wall except when stopped by the middle of a stretcher. This forms what is known as sectional bond (see Figs. 5 and 6).

Angles

In forming angles the closer is placed next to the quoin header, and is taken through the width of the wall in English bond. In Flemish bond, if the wall is wider than 9 in., the header adjoining the quoin stretcher is cut to the length of 6¾ in. The above is also applicable to any stopped ends or jambs of walls (see Figs. 5 and 6).

Reveals

Brickwork around door and window openings can be arranged as square jambs and also as rebated jambs. These can be made 2¼ in. or 4½ in. deep according to the size of joinery to be used. The *King Closer* (see Fig. 4) is used for forming these reveals, and examples of their respective arrangements can be seen in Fig. 6. In the construction of the rebated jambs, due attention should be given to the fixing for the joinery by providing either breeze fixing-bricks or wood slips or pads, placed about 2 ft. apart in the bed joints, with the grain of the wood running parallel to the face of the wall.

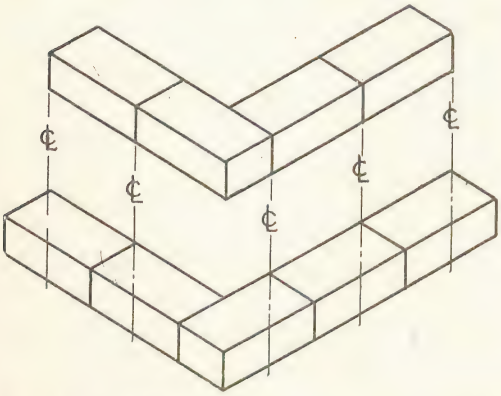


Fig. 8.—ISOMETRIC SKETCH OF ALTERNATE COURSES OF ANGLE IN STRETCHING BOND IN A 4½-IN. WALL

Squint Quoins

Angles formed that are other than the square, or right,

angle are termed "Squint Quoins" or corners.

They are divided into two kinds, and for each a special-shaped brick is used.

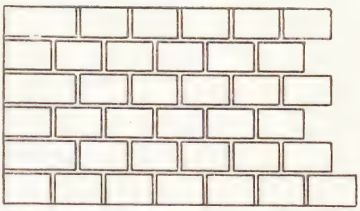


Fig. 9.—ELEVATION OF WALL BUILT IN HEADING BOND

Obtuse Angle (see Fig. 12)

For the obtuse angle, a brick is either cut or purposely made to the required angle, and has usually a $2\frac{1}{4}$-in. face on one side and $6\frac{3}{4}$-in. on the other. When using this brick it is usual to regard the $2\frac{1}{4}$-in. side as the header side of the brick, and a queen closer is placed against this side to obtain a $2\frac{1}{4}$-in. bond.

Sometimes, however, it is necessary to shorten the $6\frac{3}{4}$-in. face to $4\frac{1}{2}$ in., in order to prevent using broken bond in the wall or to obtain the strongest arrangement in a pier, and then the closer is eliminated and the quoin brick is placed to suit the job and to make it as strong a tie or bond as possible. Care should be taken, when filling the irregular-shaped pieces of brick in the internal part of the wall, to see that no excessive amount of mortar is used to make up the deficiency of a badly cut brick.

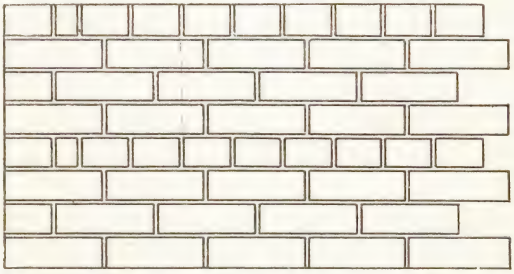


Fig. 10.—ELEVATION OF WALL BUILT IN ENGLISH GARDEN WALL BOND

The arrangement of bonding to squint quoins can be made strong if the general principles of bonding and the above remarks are adhered to.

Acute Angles (see Fig. 13)

When formed, the bond is arranged in a somewhat similar manner as that for the square quoin, except that it is sometimes necessary to reduce the size of closer due to length of the header side of the quoin brick. The sharp arris or corner is usually either rounded or blunted, as it is apt

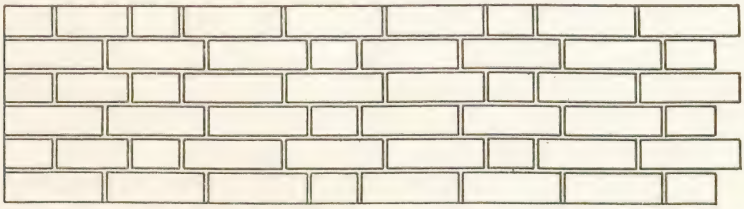


Fig. 11.—ELEVATION OF WALL BUILT IN FLEMISH GARDEN WALL BOND

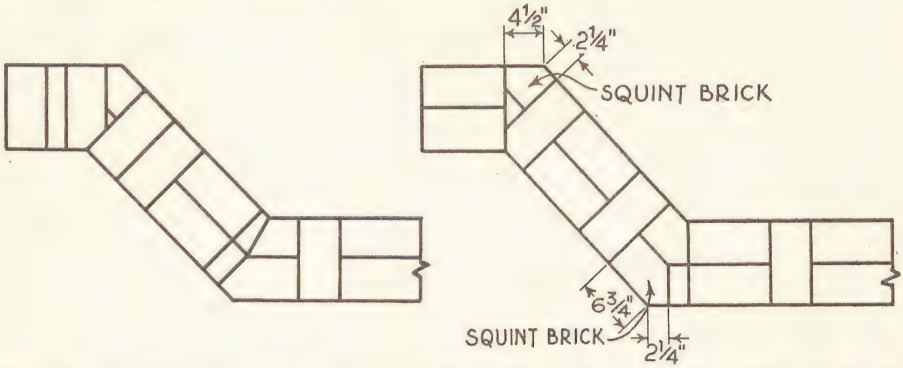


Fig. 12.—ALTERNATE COURSES OF DOUBLE FLEMISH BOND TO OBTUSE SQUINT QUOIN IN 9-IN. BRICK WALL

to prove dangerous to passing traffic, and owing to the slenderness of the extremity of the brick, which is easily subject to damage.

The quoin bricks for the acute angle are sometimes referred to as splays or splayed bricks.

Cutting the Squint Bricks from Ordinary Building Bricks

It is often necessary to shape quoin bricks from ordinary bricks, and to do this a wood mould or template is made of the proposed shape, and this is placed on the brick to be marked. The brick is then cut with the hammer and bolster, and the faces made further smooth with the use of the scutch.

It will be seen that only in internal work can acute quoin bricks be cut from ordinary building bricks, because the splay cut would come into the frog of the brick, which would require to be filled in with stopping to make it appear as a whole brick.

A further treatment of acute quoins can be seen in Fig. 14.

It will be noted that the external angle is formed with ordinary facing bricks, and this arrangement is mostly used when a corner of this kind occurs in a wall adjoining a public road or footpath.

Rebated and Splayed Jambs

In wide walls it is often the practice to splay the inside jambs of window openings and so enlarge the opening. It takes off the heaviness of the width of the wall, and admits more light. The external part of the reveal is arranged as for the square reveals; but for the splayed jamb, squint bricks are used to form the angle. (For example, see Fig. 15.)

Junctions to Walls

As far as possible, the principles of bonding square quoins are applicable to the bonding of walls adjoining at right angles to each other. The

positions of the relative walls often make this impossible, and it is then that the craftsman will have to arrange the bonding to the best advantage. It is best to give as much lap as possible to the course bonding in the adjoining wall, and endeavour, as far as can be arranged, to commence with the correct formation of the particular bond in question. (For example, see Fig. 16.)

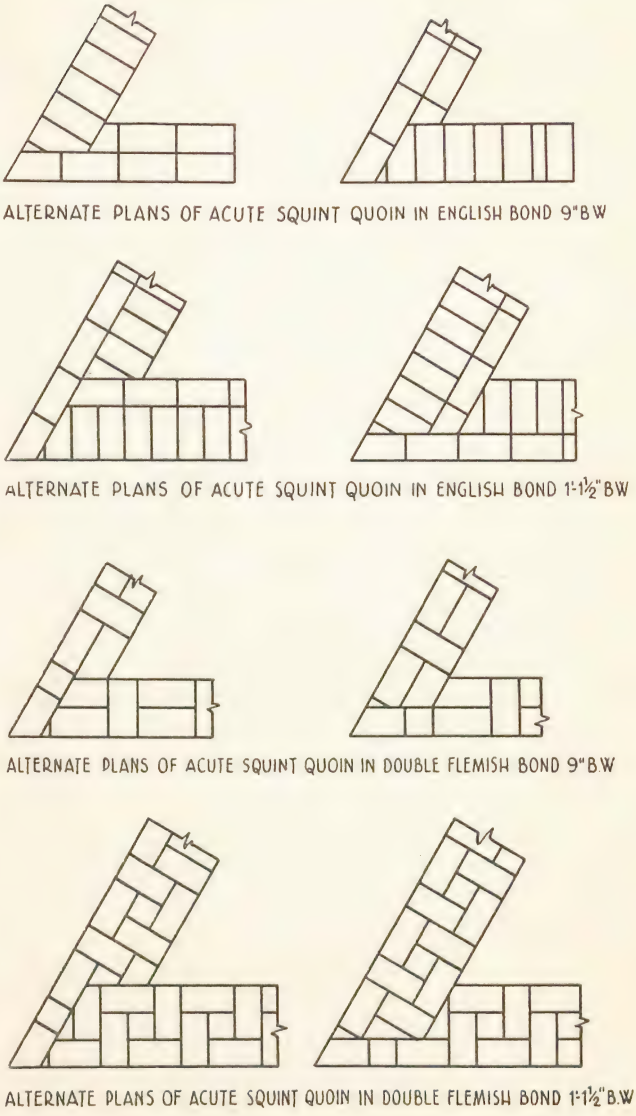


Fig. 13.—ALTERNATE PLANS OF ACUTE SQUINT QUOIN IN VARIOUS TYPES OF BONDS

Intersections or Cross-walls

Junctions in walls of this kind are usually found in the internal parts of buildings. The bond must be arranged so that a complete alternate lap of each wall is made across the other.

It is sometimes necessary, when all the faces of the wall are exposed as the finished surface, to arrange the brickwork from all of the internal angles to match. This causes an irregularity in the continuity of the double Flemish bond, and the portion of the bonding wall between the internal angles is arranged to suit the job (see Fig. 17).

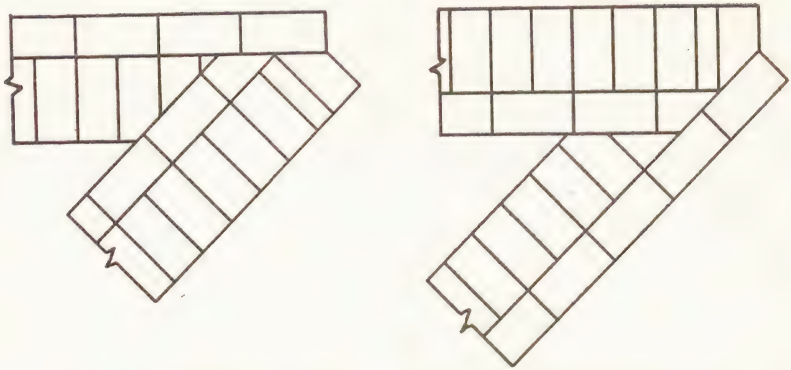


Fig. 14.—ALTERNATE COURSES OF ENGLISH BOND TO AN ACUTE ANGLE IN A 1-FT. 1½-IN. WALL, USING ORDINARY BRICKS TO FORM THE QUOINS

Bonding to Piers

The term pier is used where walls are divided into small portions and continue as such, to be later on joined in the main walls of the building. This kind of pier is usually made the same width as the walls, and the bonding made to match. Square piers, as often as not, are a separate unit from the main walls, being designed to carry the load of a rolled-steel joist or stanchion, etc. Their purpose, therefore, governs the size, and they can be built in English or Flemish bond.

Fig. 18 shows examples of the bonding for these piers, and it must be noted that in the 1-ft. 1½-in. pier in English bond all the bricks have been reduced in length to 6¾ in., while if a pier of this size be arranged in Flemish bond to appear on all faces, the pier becomes only a 4½-in. casing. It is therefore advisable, when requiring a Flemish arrangement, to combine both English and Flemish, which forms a better and stronger bond.

Adjoining, or Attached, Piers

Piers are frequently placed against walls to give extra support, acting as buttresses, or to take point loads, and sometimes as an ornament to break up the continuance of long blank walls.

In the construction of the piers, the bonding must be arranged so that an alternate bond is made into the main or adjoining wall. The bond must also be sectional, and in some instances it will be found that broken or irregular bond

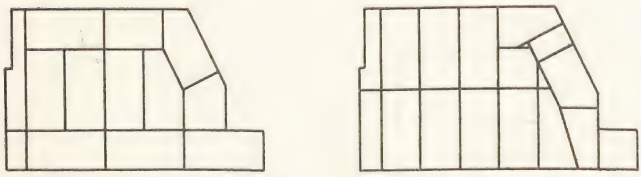
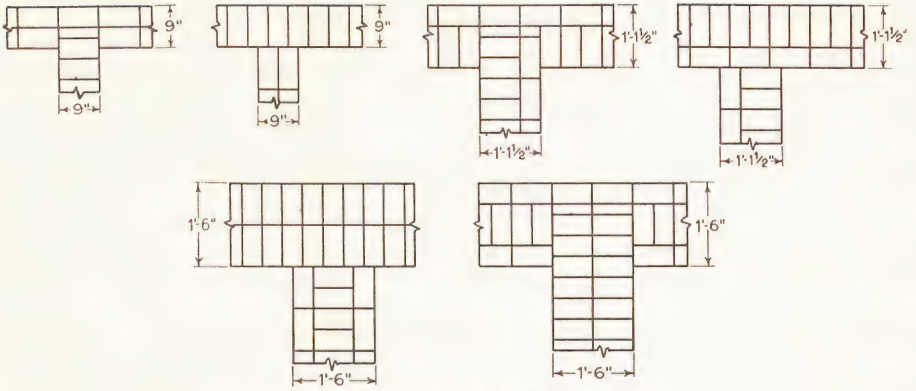
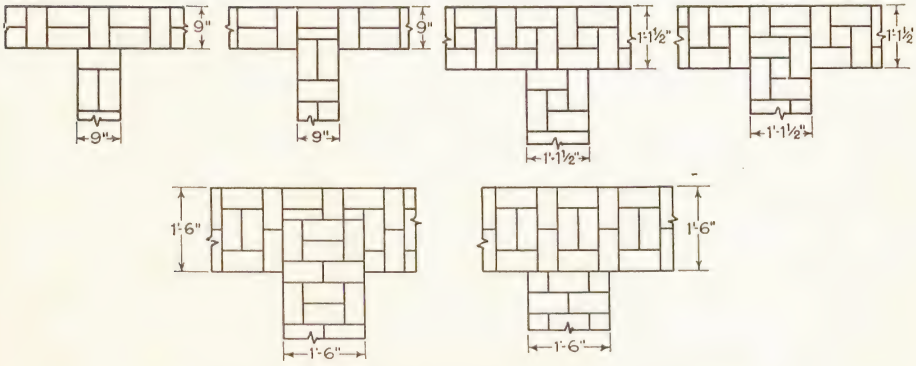


Fig. 15.—ALTERNATE COURSES OF 4½-IN. REVEAL AND 4½-IN. REBATED AND SPLAYED JAMBS TO 1-FT. 6-IN. WALL, ENGLISH BOND



JUNCTION OF WALLS IN ENGLISH BOND



JUNCTION OF WALLS IN DOUBLE FLEMISH BOND

Fig. 16.—ENGLISH AND DOUBLE FLEMISH BOND JUNCTIONS

will have to be used in the adjoining wall to do this (see Fig. 19).

Arrangement of Brick Bonding to Foundations

Brickwork to the base of walls is usually made twice the width of the actual wall on the bottom course, and reduced in regular $2\frac{1}{4}$-in. offsets each side until the required width of wall is reached. The bricks are laid headerwise as far as possible, and any half-bricks that occur in the width are placed in the middle of the wall.

In setting out the bond for an angle, a three-quarter bat should be placed next to the quoin header and must be taken across the width of the wall. These should be staggered or placed immediately behind the two headers, or more according to the size of wall, that follow on past the quoin stretcher. This is repeated in all the offset courses, and it will be

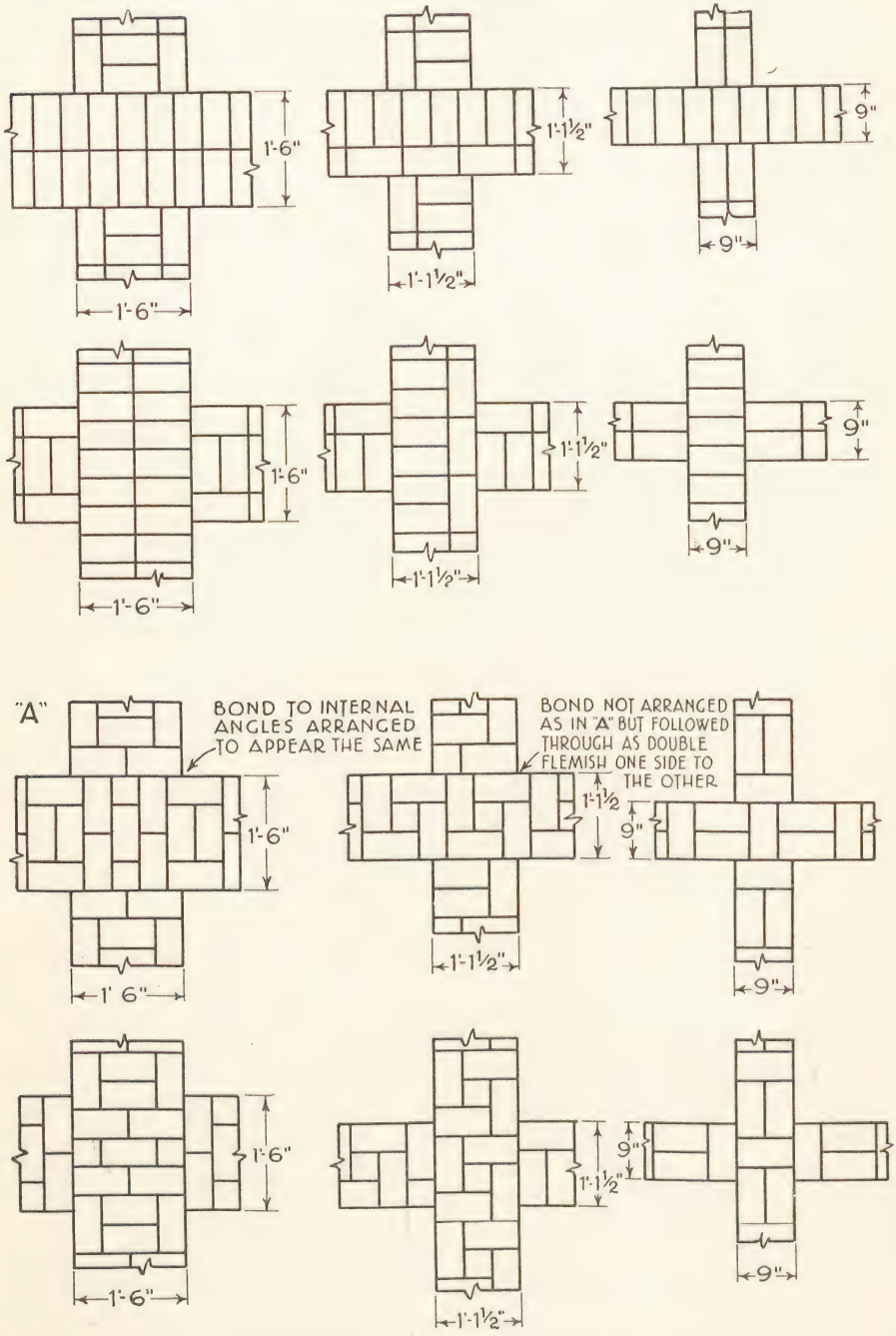


Fig. 17.—INTERSECTIONS OF WALLS, ENGLISH AND FLEMISH BONDS

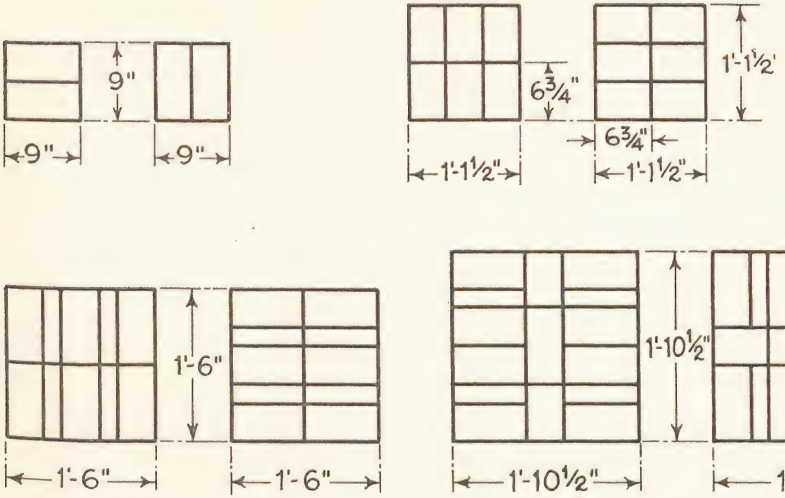


Fig. 18.—ALTERNATE PLANS OF SQUARE PIERS IN ENGLISH AND DOUBLE FLEMISH BONDS

possible to set out the neat or actual wall with a closer next to the quoin header, and have every brick making a quarter-bond with the footing courses.

This arrangement, shown in Fig. 20, is simple, and is more satisfactory than the more often used practice of building a course of headers in each

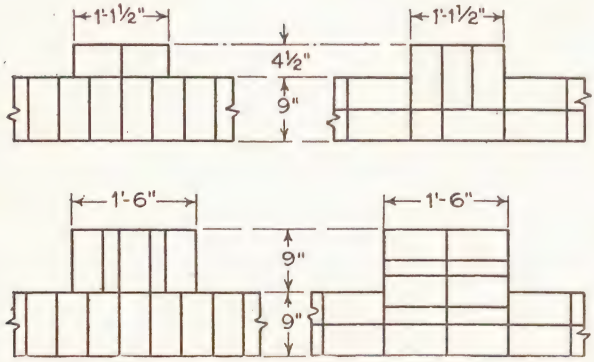


Fig. 19.—PLANS OF ALTERNATE COURSES OF ADJOINING PIERS

course of the footings without the three-quarter bat, so that when the actual wall is reached, on one side or the other a continuance of straight joints, or joints vertically over one another, is revealed.

Bonding to Hollow Walls

In exposed situations, in order to prevent driving rains from penetrating the walls, they are often erected as a double wall with a small cavity between them. The external wall is usually a 4½-in. brick wall, and is bonded to the internal wall with galvanised or tarred and sanded iron wall ties. These are placed not less than 3 ft. apart, in a diagonal manner, and care must be taken to ensure that all angles, jambs, and reveals are properly bonded with them. The outer wall is usually built in stretching bond, but sometimes Flemish bond is required, and then it is necessary to snap or make the headers 4½ in. in depth.

Foundations of Cavity Walls

In the foundations of cavity walls it is usual to have footings in a similar manner to those for solid walls, keeping the regular 2¼-in. offsets on the outside of the wall. Those occurring on the inside are sometimes used as a foundation for a sleeper wall or wall supporting the floor joists.

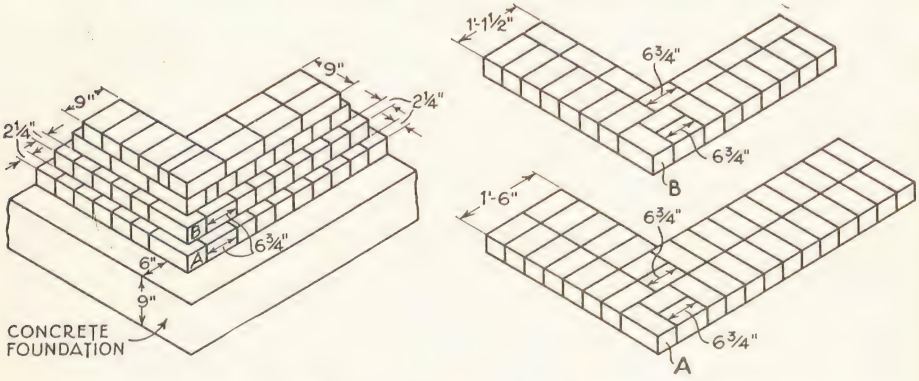


Fig. 20.—FOUNDATIONS FOR WALLS

Left, isometric drawing of footings and foundations for a 9-in. wall; right, isometric drawing of bonding to courses A and B.

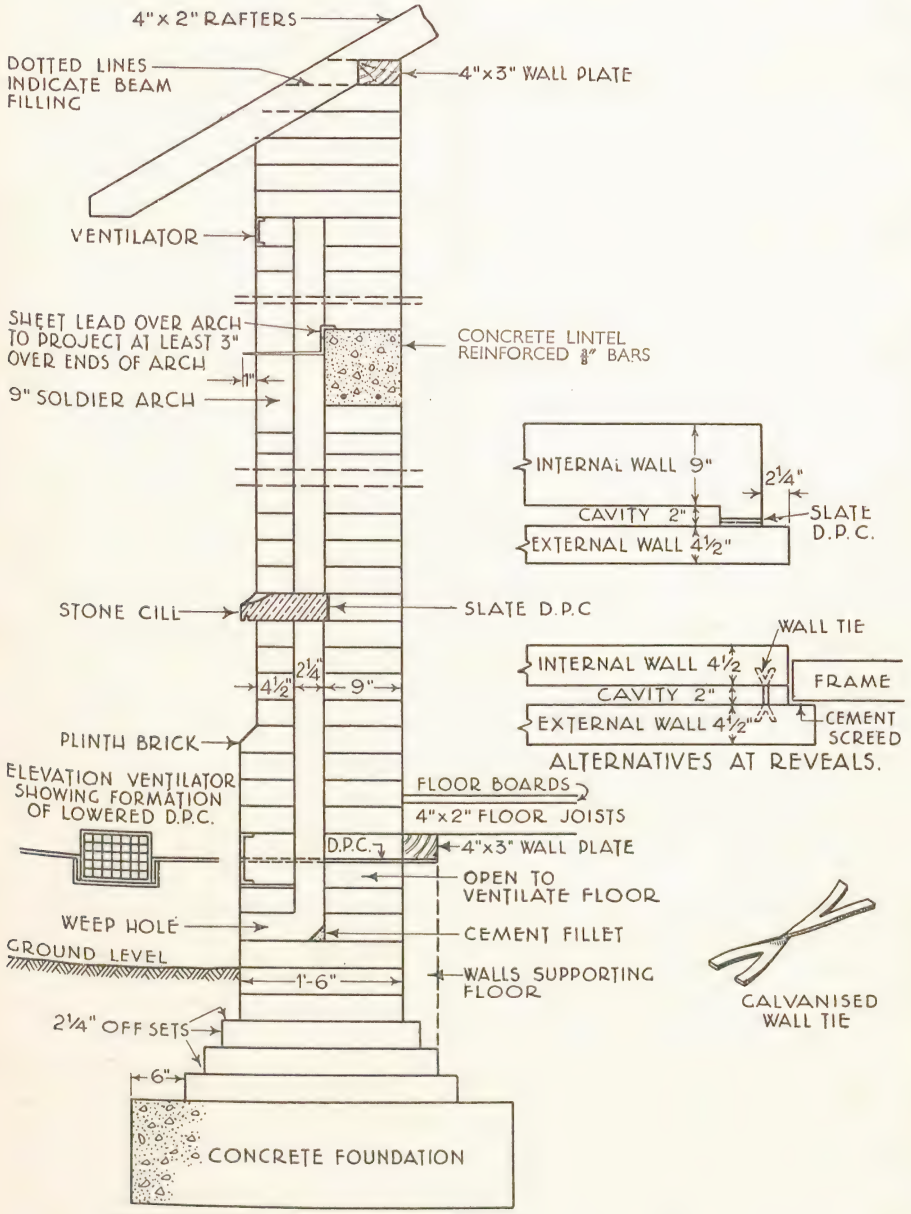


Fig. 21.—TYPICAL SECTION THROUGH CAVITY WALL

The cavity is best commenced just below the damp-proof course (D.P.C.), which is a layer of impervious material placed throughout the

length and breadth of all walls, just above the ground level. On the external side of the wall, small holes are left through to the cavity to permit any excess of moisture, that should percolate through the outside walls and run down inside the cavity, to escape. These holes are called weep holes.

Ventilation

The cavity must be ventilated at the top and bottom of the wall, and apertures are formed and fresh-air vents built in. These are made in terra-cotta, cast iron, and other materials.

The vents at the base of the wall are placed on the D.P.C. Fig. 21 shows an arrangement where the bed of the fresh-air inlet (F.A.I.) is 3 in. below the D.P. course which is taken down the sides and along the bottom of the vent. An aperture is then formed through the internal part of the cavity wall to ventilate the space beneath the floorboards.

The ventilator at the top of the cavity is placed immediately beneath the course of brickwork covering or sealing the cavity, and the aperture is enclosed with a fresh-air brick, as before described, in order to prevent birds or any kind of vermin from entering the cavity.

Wall Ties

Wall ties are made of galvanised iron, split at each end and twisted in the middle. Sometimes they are tarred and sanded, but the galvanised ties are more durable.

When constructing cavity walls, great care must be taken to see that no mortar droppings are left on the top of the ties, as these serve to convey dampness from the outer to inner wall if they are not properly cleaned off. In the course of construction it is best to suspend long lengths of batten, the same width as the cavity, on pieces of wire, and pull them up as the work proceeds, and so minimise the amount of droppings to be cleaned out at the bottom of the cavity at the completion of the job.

Window and Door Openings in Cavity Walls

In forming the reveals and jambs occurring in cavity walls, the outer wall is best isolated from the inner wall with a vertical D.P.C. (For example, see Fig. 21.)

The coverings to openings are best protected on the top with a piece of sheet lead turned into the joint of the internal wall, taken across the cavity and top of the external arch or lintel, and made to project about 1 in. on the external side. This should be at least 3 in. longer each end than the opening covering. If window cills are used, the back internal edge must be covered with a D.P.C., and if the cills are not wide enough to cover the cavity, the brickwork at the back is bridged over and butted to the D.P.C. adjoining the cill.

FORMWORK FOR CONCRETE BUILDINGS

THE weight of concrete depends on the aggregate of which it is composed. It may weigh about 130 lb. per cubic foot, and until it sets, the formwork must be capable of taking the weight and withstanding the pressure of the mixture.

Pressure on Formwork

Freshly mixed concrete, like water, exerts equal pressure in all directions, so the depth of the wet mixture governs the pressure. Fig. 2 shows a column 10 ft. high, and assuming it to be filled in one shift, the pressure per square foot at the bottom would be approximately 1,300 lb. In other words, with every foot in depth of concrete "placed," 130 lb. pressure is added to the bottom layer. In the case of formwork for girders and beams, it is the dead weight of the material, rather than the pressure, which must be considered. The pressure on the sides of girders of, say, 12 in. to 15 in. deep, would be about 65 lb. to 70 lb. per square foot. Nails driven through the sides into the edge of the bottom board is sufficient to take this pressure.

Fig. 1.—GENERAL CONSTRUCTION OF A REINFORCED-CONCRETE BUILDING

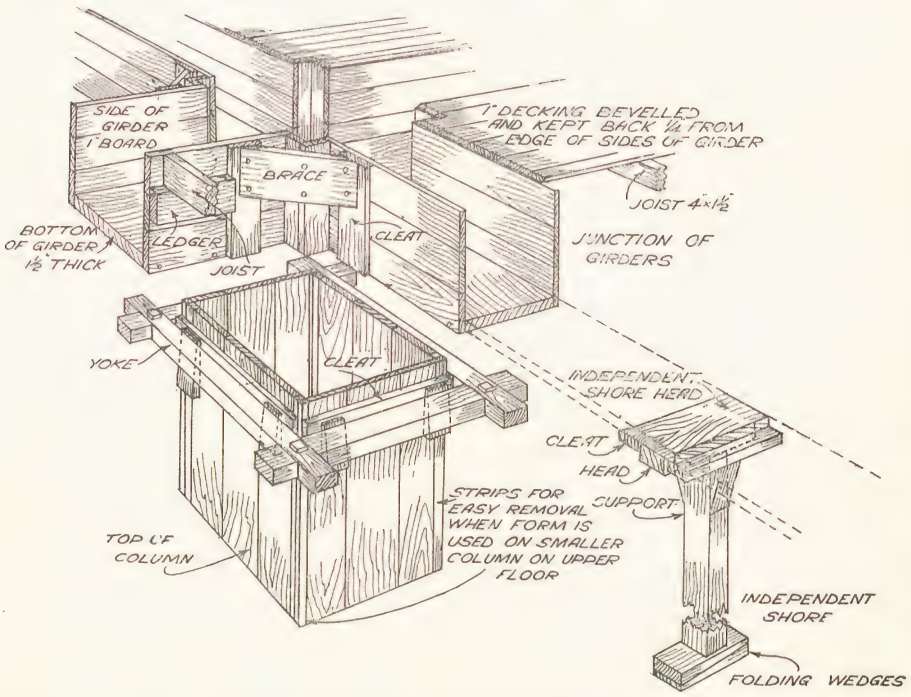


Fig. 5.—FORMS FOR JUNCTION OF GIRDERS AT B IN FIG. 1

Wall Panels, Spreaders, and Ties

Fig. 4 shows the detail of forms for lintel, edge of floor slab, and wall panel at A in key sketch. "Spreaders" are wedged between the sides to maintain the correct space, and wire ties, passed between the boards, round the cleats, and twisted as shown, take the pressure. The spreaders are removed when the concrete reaches their level. The wire ties are cut off close to the surface of the concrete, and punched below the surface, which is afterwards made good. The board for the edge of the floor slab is fixed by wires anchored to the reinforcing rods, and secured as shown.

Bevel-edged Boarding

For the reason already stated, bevel-edged boarding is used on the exposed face of the wall, while square-edged boards are used on the inside. If the joints of the inside sheeting are left slightly open, excessive swelling over the whole panel will be avoided. Expanded metal, which is held in place by the spreaders, bridges the joints between the boards, adheres to the concrete when stripping is done, and provides a key for the plaster.

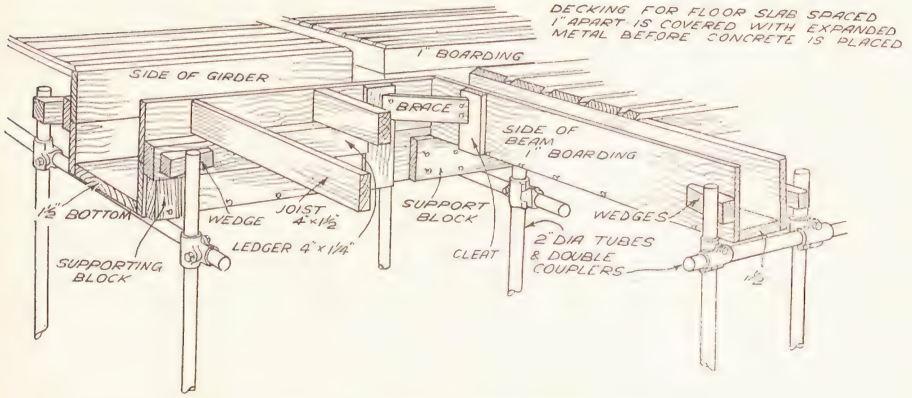


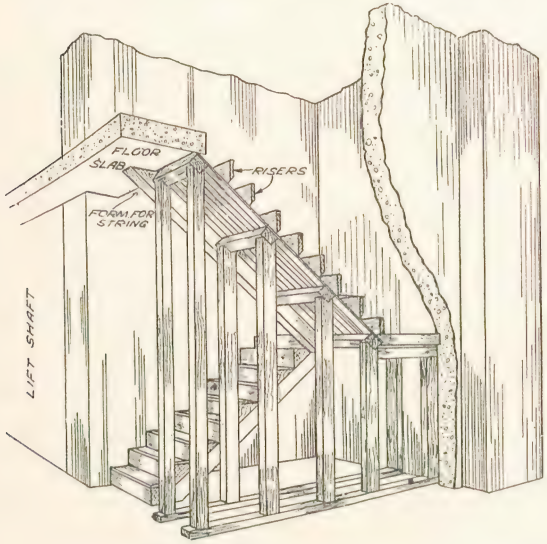
Fig. 6.—FORMWORK AT JUNCTION OF GIRDER AND BEAM AT C IN FIG. 1

Junction of Girders

Fig. 5 (detail at B in key sketch) shows the junction of girders and the top of the column form. The column form is shown with narrow strips at either edge, which when removed will make up the size of the form for the column on the next floor. The yokes are halved at the angles and bolted, and wedges keep the sides tightly in place.

Independent Shores

When the form work is stripped, for use on the next floor, it is advisable to leave one or more shores for a longer period under girders, to guard



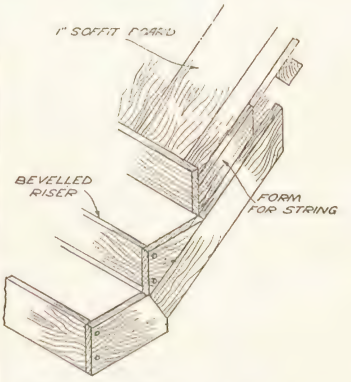


Fig. 7A.—DETAIL OF STRING AND BOTTOM STEP

Fig. 7.—FORMWORK FOR CONCRETE STAIR AT D IN FIG. 1

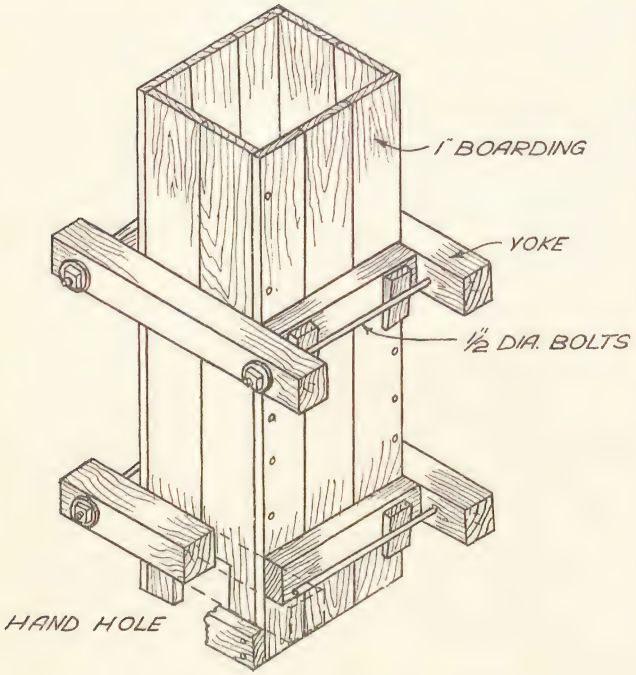


Fig. 8.—DETAIL OF FOOT OF COLUMN

against stress in the still rather "green" concrete. In Fig. 5 an independent shore is illustrated. The bottom board rests on cleats, and folding wedges are provided at the foot to allow for easy removal when that can be safely done.

Clearance

In case the sides of the girders bulge slightly, and the concrete grips the ends of the "decking," the edges of the decking should be bevelled and kept back about $\frac{1}{4}$ in. from the edges of the girder (see Fig. 5).

Junction of Girder and Beam

The junction of a girder and beam is shown in Fig. 6 (detail at C in key sketch). Here the decking is shown, with spaces of about 1 in. between the boards. Fine-gauge expanded metal bridges the gap, and forms a key for the plastered ceiling.

Supports for Formwork

Tubular scaffolding is shown supporting the formwork. It can be used time and again, so apart from first cost it is in the end most economical. Shores which can be adjusted to suit the required height are obtainable, and are extensively used.

Stairs

The formwork for stairs in concrete is shown in Fig. 7 (detail at D in key sketch). Fig. 7A shows a detail of the string and bottom step. The studs supporting the soffit boarding should be racked together; the

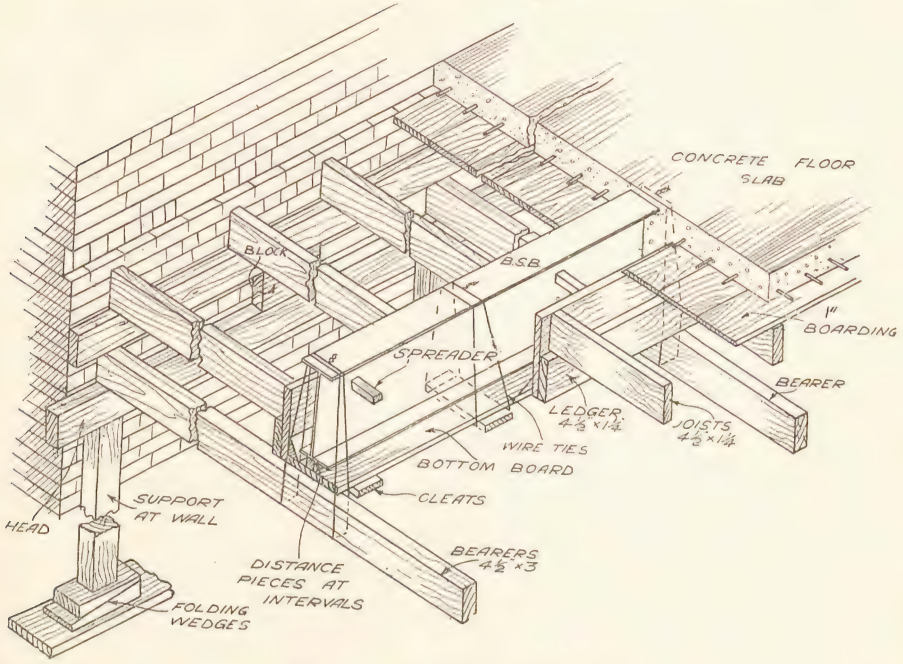


Fig. 9.—SUSPENDED FORMWORK

racks are not shown in the sketch. The concrete is finished level with the top of the risers, which are bevelled on the bottom edge to allow the floating off of the surface to be performed.

Hand Hole

Shavings and other rubbish are apt to collect at the bottom of column forms. If a small hand hole, as shown in Fig. 8, is provided, rubbish can be removed just prior to the concrete being placed. Another type of yoke is here shown, in which ½-in. diameter bolts are used to keep the sides tightly together. The end panels are nailed direct to the yokes, and wedges driven between them and the bolts.

Suspended Formwork

In steel concrete construction, the beams are used to support the forms for the haunch, soffit, and decking of floor slab. Wire ties, at intervals according to the weight to be carried, are passed between the sides and bottom boards to support bearers, as shown in Fig. 9. The bearers take the weight of the beam form, and additional support may be given by ties at intermediate cleats. Spreaders between the web of the beam and the sides maintain the correct width. Distance pieces (small

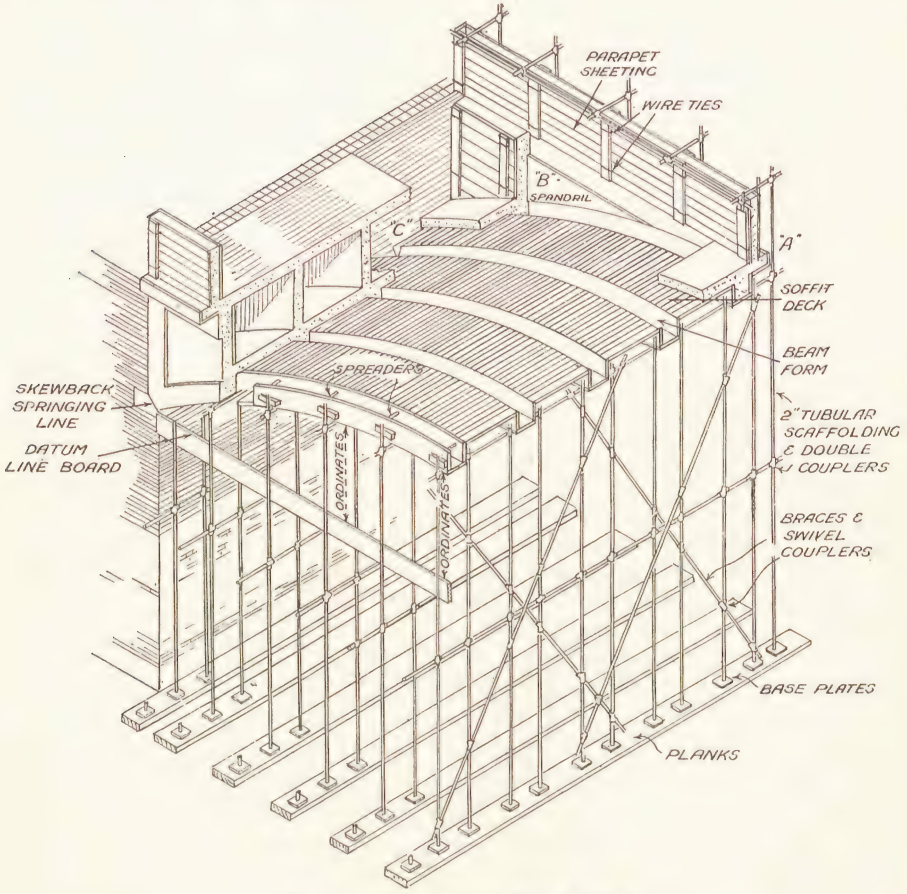


Fig. 10.—FORMWORK FOR BRIDGE

pieces of concrete) at intervals under the bottom flange ensure the correct thickness of concrete. The ledgers on which the joists rest are supported by the bearers, and lightly nailed to the sides. The decking is bevelled where it rests on the sides of the beam, and is kept back $\frac{1}{4}$ in. from the inside edge for the reason already stated. The method of supporting is shown where the floor abuts on a wall.

Bridge in Reinforced Concrete

Fig. 10 shows the general construction of the formwork for a bridge in reinforced concrete. A datum-line board is fixed at the level of the spring of the arch, and from this, ordinates are taken to the under side of the curve. Horizontal tubes are fixed at these points, and the weight per foot super to be carried will govern the number of supports required.

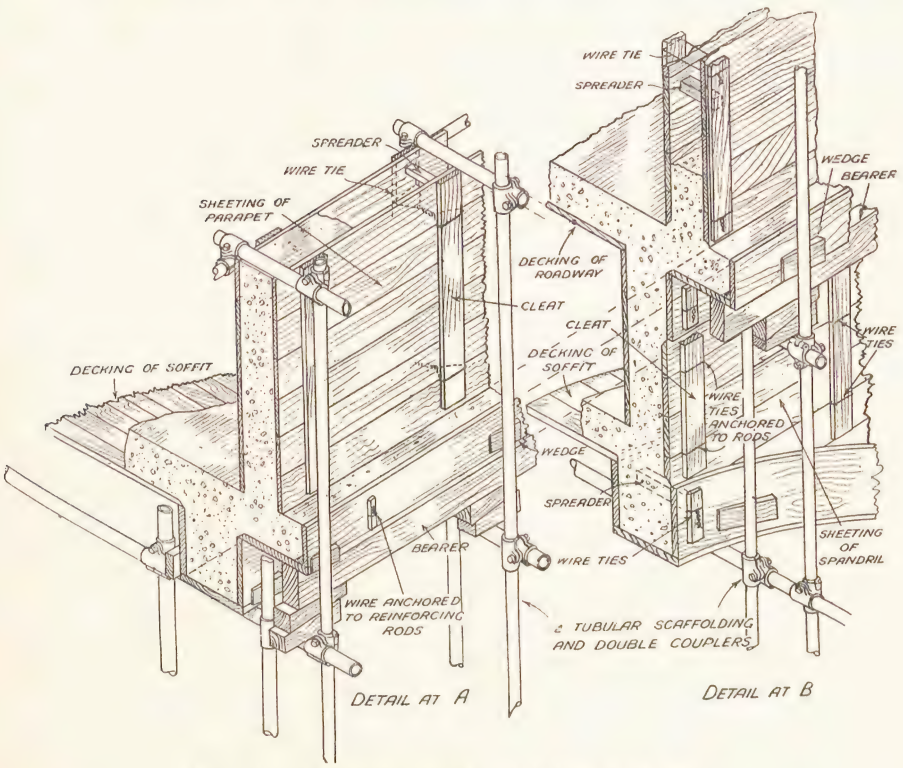


Fig. 11.—ENLARGED DETAIL OF A AND B IN FIG. 10

The top of the parapet form is stayed by securing it to a tube on the inside.

Wedges, between the sides of the beams and the top of the tube supports, keep the sides in alignment and take the pressure. Spreaders to maintain the correct width are required for the outside beams; for intermediate beams this is done by "tacking" the soffit boarding at intervals. In order that beam forms will "drop" when the stripping is done, the ends must be cut off vertical at the skewback, and a wedge-shaped portion made up to complete the curve, as shown at C.

The Top of the Parapet Form

Details at A and B are shown in Fig. 11. The top of the parapet form is stayed by securing it to a tube on the inside. The construction and details of these forms follow closely on the lines of those already described.

Metaforms

Steel forms, as illustrated and described in Figs. 12 and 13, are obtainable. Metaforms for circular work can also be supplied.

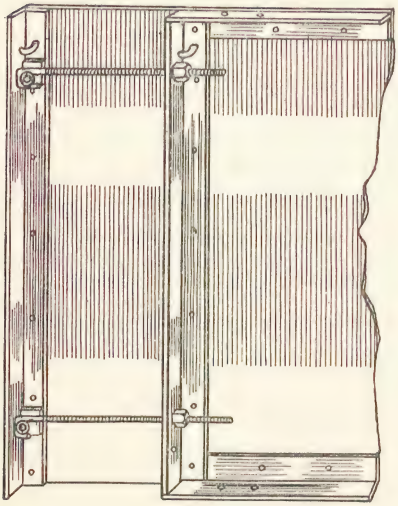


Fig. 12.—ADJUSTABLE "METAFORM" UNIT FOR CONCRETE CONSTRUCTION

The steel units are assembled into walls of required length, height, and shape, and each unit is clamped to its neighbour by unbreakable malleable clamps. These units are particularly useful for adjusting the overall length of the formwork assembly.

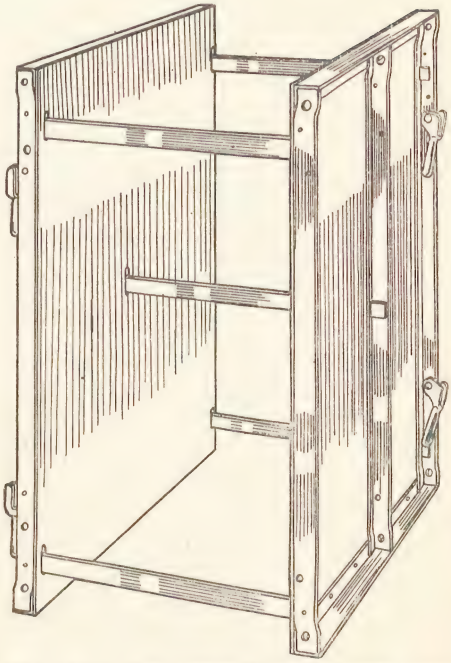


Fig. 13.—"METAFORM" STEEL SPREADER TIE SHOWING THE USE OF THE MAXIMUM NUMBER OF SPREADER TIES

QUESTIONS AND ANSWERS

What is the average weight per cubic foot of concrete ?

About 130 lb. per cubic foot.

What would be the side thrust at the bottom of a 10-ft. high column of wet concrete ?

1,300 lb. per square foot.

What would be the side thrust in the same column at a height of 5 ft. from the ground ?

650 lb. per square foot.

What precautions should be observed in nailing formwork ?

(1) It should be nailed as lightly as possible.

(2) The nails should be left with their heads scarcely driven home, so that they can be drawn out with a claw hammer.

(3) The nails should be driven slightly on the angle.

What size boarding is usual for the panels of columns and the sides of girder forms ?

One-inch boarding is usual.

What rules should be observed in the spacing of yokes for concrete formwork ?

The yokes should be spaced close together near the base, where the pressure is greatest. In the case of a 10-ft. column using boarding 1 in. thick, the bottom yokes should not be more than 18 in. apart. The next yoke should be placed at a height of 3 ft. 6 in., the third at a height of 6 ft., and the fourth at a height of 9 ft.

What is the usual practice adopted when erecting forms for concrete columns ?

It is common practice to make the forms for columns a little more than half the complete height, to " place " the concrete, and when this has set sufficiently hard, to move the half-form up and place the remainder.

What precaution can be taken to facilitate " stripping " of formwork ?

A coat of soft soap and water on formwork will facilitate stripping and leave a better face on the concrete.

What timber should be used if the surface of the concrete is required to be left smooth ?

The boarding must be " thicknessed " as well as wrought to avoid ridges.

Is this necessary if the surface is to be plastered ?

No, because a rough and ridged surface will be an advantage in providing a " key " for the plaster.

If the timber used for formwork is " bone dry," will this cause any trouble ?

Timber that is " bone dry " tends to " cast " and swell when the wet mixture is placed, and in wide panels this might be considerable.

What precautions can be taken to avoid this ?

(1) Bevel-edged boarding may be used ; the sharp edges will " give " and avoid the accumulated expansion over the whole panel.

(2) By damping the outside of the panel, casting will also be avoided.

What precaution should be taken when stripping formwork for use on another floor ?

It is advisable to leave one or more shores for a longer period under the girders, to guard against stress in the still rather " green " concrete.

What precaution should be taken when erecting column formwork ?

A small hand hole should be left at the bottom to enable shavings and other rubbish to be removed just before the concrete is placed.

SOUND-INSULATED CONSTRUCTION

SOUND insulation is becoming of increasing importance, and the tendency to thin down dividing walls greatly increases the problems of the acoustical engineer. The theory of the subject is incomplete, and attempts at sound-proofing are not always attended with success, even though the underlying theoretical principles for adequate insulation are adhered to. Sound progresses with apparent facility through solid constructions, by paths which it is not always easy to trace, and may be heard in positions quite remote from the source of the sound. The extreme sensitivity of the ear accounts for the difficulty of completely insulating a structure against the intrusion of external sound.

Air-borne sounds may be transmitted to an adjoining room in three ways :—

(*a*) By direct passage of air waves through openings in the wall, through ventilators, etc.

(*b*) By vibration of the dividing medium itself as a diaphragm which by its motion re-creates sound waves on the farther side ; and

(*c*) By direct transmission of elastic-wave motion through the dividing medium which imparts to the air at the farther side a wave motion exactly timed to that of the origin.

Insulation

Air-borne sounds are most effectively stopped by rigid walls that do not have openings for pipes or ventilators, though the construction of the wall itself, apart from the question of rigidity, has an important bearing upon the degree of insulation.

For the transmitted sound to be a minimum—i.e. for the greatest sound insulation—the sound energy dissipated in other ways must be a maximum.

(*a*) The reflected sound will be large in proportion to the incident sound if the reflecting surface is " hard."

(*b*) The sound absorbed by conversion to heat energy will be increased by using " laminated " construction, with the inner layer very absorbent of sound.

(*c*) The sound energy absorbed as mechanical energy will be increased by using heavy, " massive " construction.

(*d*) The diaphragm-like vibration can be minimised by the adoption of " rigid " construction.

Rigidity

A partition may be bulged by pressure of sound, and if the periodicity of the sound waves corresponds to the natural period of vibration of the partition, the transmitted sound would be " increased " in loudness by resonance.

Measurement

Percentage figures on sound insulation are misleading, as loudness reductions are all subtractive.

The sound insulation of a partition is given as the sound reduction measured in decibels.

The transmission ratio for a partition is the ratio which the sound energy transmitted through the test partition bears to that transmitted through the uncovered aperture when the partition is removed.

The reciprocal of the transmission ratio is known as the reduction factor, and ten times its logarithm represents the fall in sound level through the partition in db.

Rigid Homogeneous Construction

The test results of the N.P.L., The Bureau of Standards, Knudsen & Meyer all show that the insulation of homogeneous partitions is proportional to the log. of the weight per square foot.

From the average curve of the results the following relation is found to exist :—

Insulation in db. $= 14{\cdot}3 \log_{10}$ wt. per sq. ft. $+ 22{\cdot}7$ db., and the following values are of interest :—

Mass per sq. ft. of Wall Area	*Insulation in db. at 512 v.*
1 lb. wt.	22·7
5 ,, ,,	32
10 ,, ,,	37
20 ,, ,,	41
40 ,, ,,	45
60 ,, ,,	48
100 ,, ,,	51·3
400 ,, ,,	60

Davis and Littler have shown that in porous, flexible materials the sound insulation in db. is proportional to the thickness of the material.

Thus a ten-fold increase in the thickness of a flexible, porous material, like hair felt, will bring about a ten-fold increase in the sound insulation, whereas a ten-fold increase in the thickness of a rigid non-porous parti-

tion, say from 10 lb. to 100 lb. wt. per square foot, will only bring about an increase of insulation from 37 to 51·3 db., i.e. less than a two-fold increase.

Note that to provide an insulation of 60 db. by means of a solid non-porous wall, a mass of 400 lb. per square foot would be necessary—say a 40-in. brick wall.

Owing to the slow rate of increase of insulation with weight of partition it is generally uneconomic in practice to provide for insulation greater than 45 db. solely by mass and rigidity.

In panels of homogeneous nature, mass and rigidity are the determining factors, but when the construction departs from homogeneity, structure becomes of predominating importance.

Composite Construction

In order fully to appreciate the action of sound insulation and its effect upon the design of "soundproof" structures, the reader should bear in mind that transmission of sound may take place either by acoustical refraction in the dividing medium or by the membrane-like vibration of the whole.

The proportion of incident sound energy reflected from a rigid non-absorbent material is normally exceedingly high.

This means that the balance of sound energy refracted through the dividing medium and transmitted is exceedingly small. Indeed, it may be assumed in practice that refraction effects may be ignored, and that it is necessary only to consider the diaphragm-like vibrations.

An increase in stiffness and/or mass will, therefore, improve the sound insulation of a wall.

In cavity construction, cross-connections are very detrimental to the sound-insulating value of lath and plaster or similar partitions. The one side should be constructed entirely independent of the other by the use of staggered studding.

In the cavity an air space is generally better than a filling material, unless the filling material is quilted (to prevent its settlement and tight packing) and fixed to one side only.

Conclusions

Undoubtedly the important points for the prevention of sound transmission in walls and partitions are :—

(*a*) A hard reflecting surface on the outside of the wall.
(*b*) A non-homogeneous structure containing inert air cells.
(*c*) An air gap to prevent continuity.
(*d*) A layer of insulating material.
(*e*) A sound-absorbent surface facing the other room.
(*f*) A massive and rigid construction.

Floors

In the case of floor construction, not only have we to deal with air-borne sounds, as in the case of the previous discussion for walls, but contact noises, produced by vibration communicated directly to the structure, are introduced.

Tests have shown that the important points for the prevention of sound transmission through floors are :—

(1) A floating floor isolated from the walls.

(2) An isolating material of non-homogeneous nature between the floor-covering and the floor proper.

(3) The floor proper (of massive and rigid construction) ; and

(4) A suspended ceiling.

Test Results

The results on the sound insulation of various constructions for walls, partitions, and floors are given in the Builders' Data Sheets Nos. 8, 9, and 10.

The tests are authoritative, but the results may not entirely represent those obtaining in practice, as structural resonance, edge-fixing conditions, and workmanship in construction all affect the insulation obtained.

QUESTIONS AND ANSWERS

How are air-borne sounds transmitted to an adjoining room ?

(1) By direct passage of air waves through openings in wall, or through ventilators, etc.

(2) By vibration of the dividing medium itself as a diaphragm, which by its motion re-creates sound waves on the farther side.

(3) By direct transmission of elastic-wave motion through the dividing medium, which imparts to the air at the farther side a wave motion timed to that of the origin.

What is the most effective method of stopping air-borne sounds ?

By rigid walls that do not have openings for pipes or ventilators, though the construction of the wall itself, apart from the question of rigidity, has an important bearing upon the degree of insulation.

What are the important points for the prevention of sound transmission in walls and partitions ?

(1) A hard reflecting surface on the outside of the wall.

(2) A non-homogeneous structure containing inert air cells.

(3) An air gap to prevent continuity.

(4) A layer of insulating material.

(5) A sound-absorbent surface facing the other room.

(6) A massive and rigid construction.

ARCHITECTURAL ACOUSTICS

ARCHITECTURAL acoustics deals with the science of sound in its relation to buildings, and the scope of the subject as dealt with in this article is limited to the sections enumerated below :—

(1) The provision of proper acoustical conditions in auditoria, including :

(*a*) Problems demanding acoustical study in design.

(*b*) Acoustical correction of auditoria after construction.

(2) The absorption and dissipation of noise by acoustical methods.

The problems of sound insulation are dealt with in a separate section on Sound-Insulated Construction.

Sound

Sound is a form of energy which finds its origin in vibration of matter, by which medium it is also propagated.

The frequency range of audible sound covers about 10 octaves, from 20 to 20,000 cycles per second, and its position on the spectrum of vibration can be observed from Figs. 1 and 1A.

Characteristics of Sound

There are three principal characteristics of sound :—

(1) *Pitch*, proportional to frequency, which is measured by the number of complete waves passing in one second.

(2) *Loudness*, which is the comparative statement of the strength of the sensation received through the ear. A loudness scale is given in Fig. 2.

(3) *Tone Quality*, which is that characteristic of a sound which distinguishes it from another of the same loudness and pitch.

All sounds are composite, consisting of a fundamental note and its overtones, all of which are essential to the maintenance of undistorted tone.

The Decibel

As the decibel is referred to in many places it may be advisable to give a definition of the term.

The decibel is a unit of the ratio of two powers, and these powers may themselves be expressed in any convenient set of units. Since the decibel is the unit of a ratio, it differs in conception from units like the pound or foot.

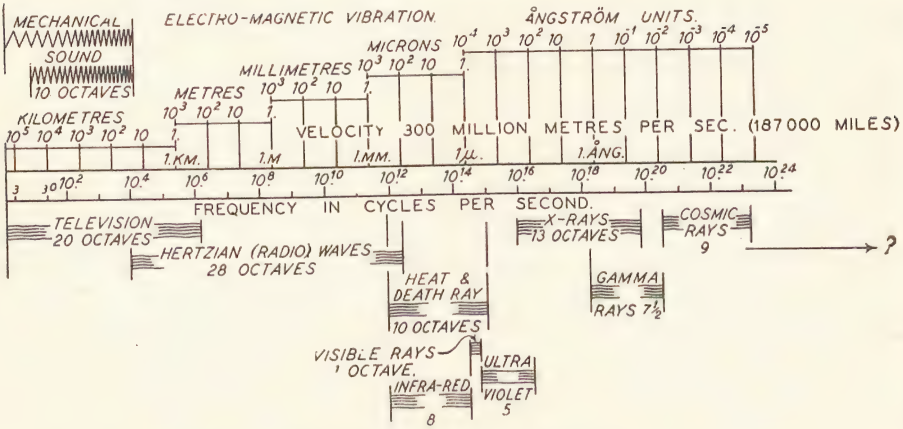


Fig. 1.—SPECTRUM OF VIBRATIONS

Suppose we have two sound fields having different intensities (i.e. energies or powers) P_1 and P_2, then the difference in level between the two sound fields in decibels is given by :—

$$n \text{ db.} = 10 \log \frac{P_1}{P_1}$$

The Acoustical Requirements of Buildings

Figs. 3A and 3B, illustrating the evolution of the theatre, indicate the development of the problems of architectural acoustics.

The addition of the roof structure, as shown, produced the first theatre which not only provided protection against the elements, but prevented the dissipation of the sound into space, conserved the sound energy, and by reflection and inter-reflection within the building introduced a new phenomenon—that of reverberation. Improved as was the building for uniform hearing conditions, acoustical defects due to shape, structure, decoration, and arrangement introduced problems hitherto unknown.

The General Requirements for Good Acoustics in Buildings

These may be briefly stated as below :—

(1) Uniform distribution of sound throughout the room, without distortion.

(2) Proper reverberation time.

(3) Adequate loudness of sound throughout the room.

(4) Absence of disturbing extraneous noise.

Acoustical Defects

A summary of acoustical defects, their causes, recommendations for their avoidance in design, and the remedy to be applied in existing buildings, are given in the table on page 149.

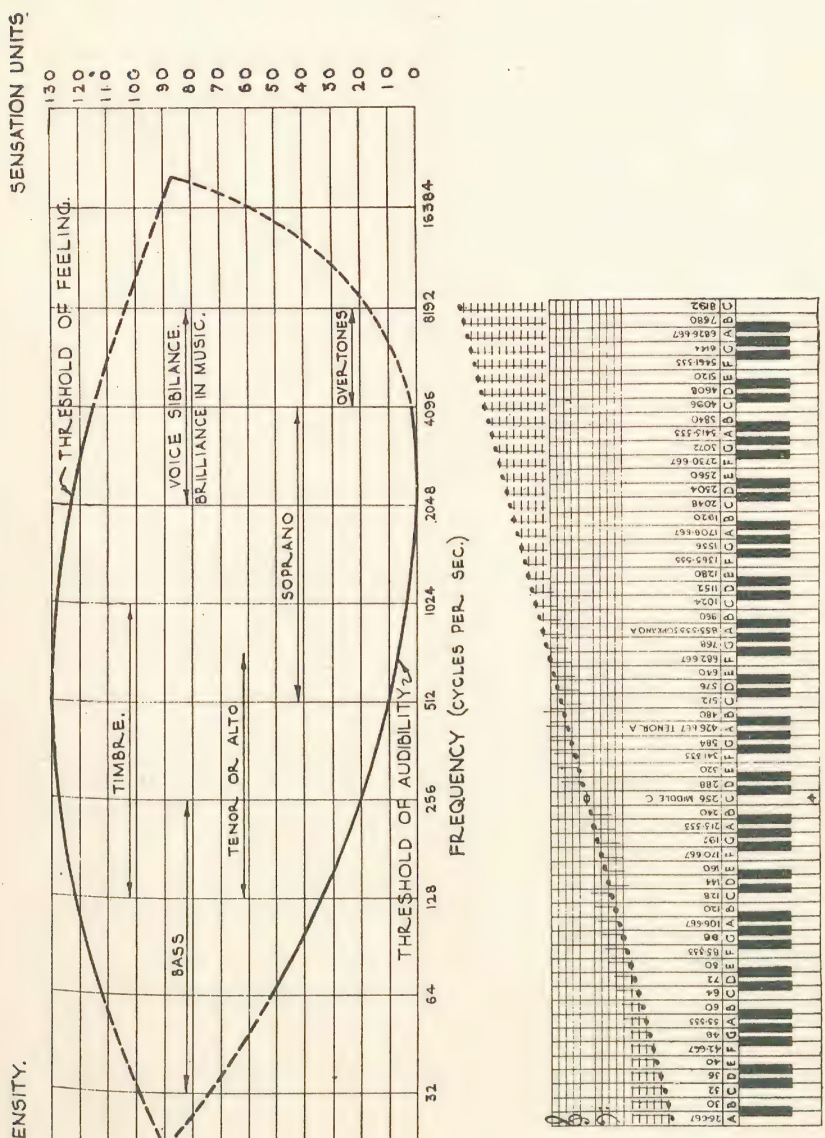


Fig. 1A.—AUDITORY SENSATION AREA

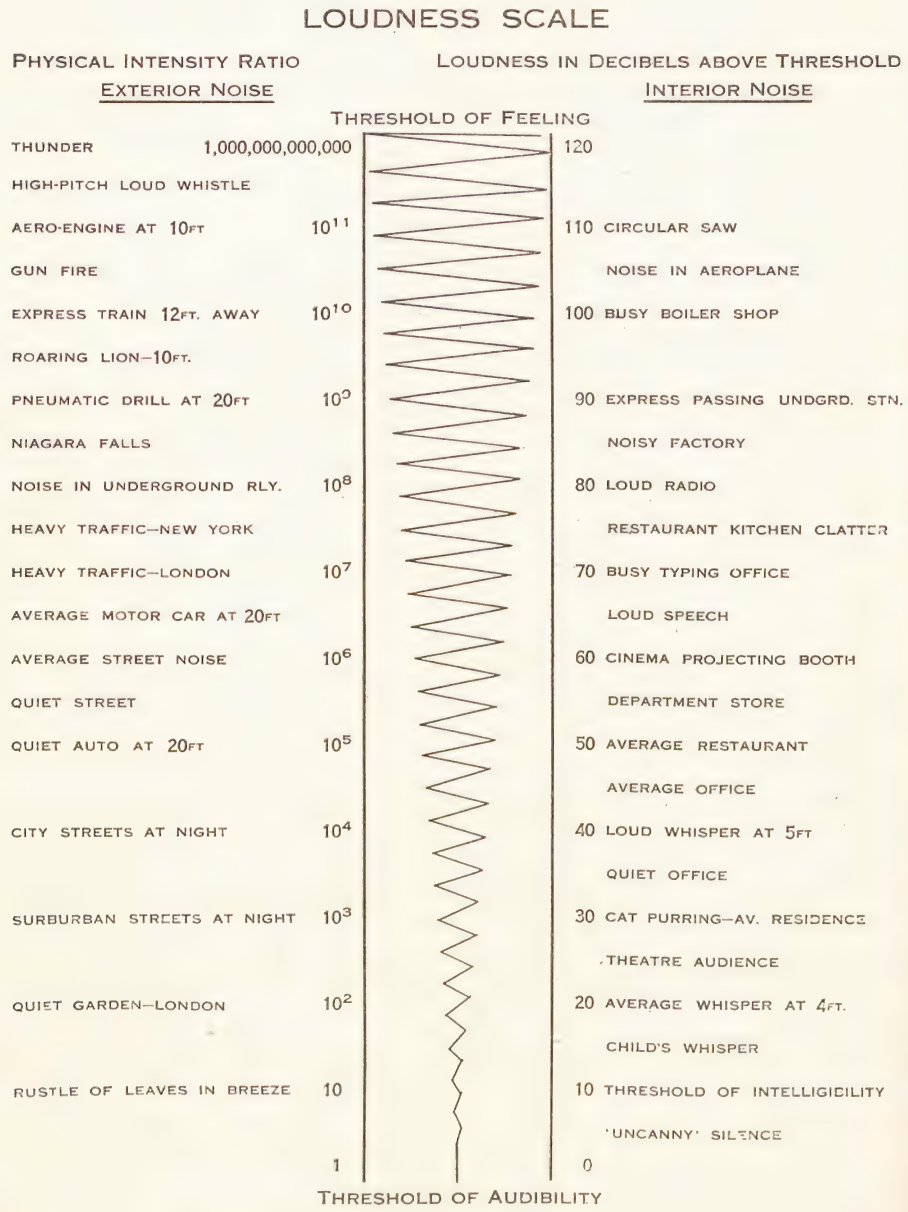


Fig. 2.—LOUDNESS SCALE

SUMMARY OF ACOUSTICAL DEFECTS

Defect	*Causes*	*Avoidance in Design*	*Remedy for Existing Buildings*
Excessive reverberation	A. Excessive volume	Keep volume down to 100–150 cu. ft. per seat	Increase seating, reduce volume, or increase interior surface by bold decoration
	B. Insufficient absorption	Add absorbents	Add absorbents
Echoes	A. Unsuitable shape	Avoid curves in design	Alter shape, or use absorbents on offending surfaces
	B. Distant reflecting surfaces	Make distant surfaces highly absorbent	Ditto ditto
Sound foci ..	Concave reflecting interior surfaces	Avoid curvilinear interiors	Alter shape or use absorbents on focusing areas
Dead spots ..	A. Positions denuded by sound foci	Avoid curvilinear interiors	Alter shape, make focusing area absorbent. Use parabolic sounding boards, or directional speakers
	B. Screens	Reflect sound into screened areas	
Interference ..	Undiffused reflections of sustained note	Design bold breaks in walls and ceiling. Use resonating wall covering	Add bold decorative and/or resonating interior treatment
Insufficient sound volume	A. Too voluminous a building	Use orchestra of appropriate size. Use electrical amplification	
	B. Lack of reflection close to origin	Dispose hard, reflecting surfaces about origin	
	C. Excessive absorption	Adjust absorption to give optimum reverberation	
Distortion ..	A. Selective absorption	Use of collection of absorbents to obtain uniform coefficient	
	B. Screening of higher frequencies	Avoid screening sound	Reflect higher frequencies into sound shadows
	C. Uncontrolled resonance	Select board absorbents which resonate over wide range, and fix on battens at irregular intervals	
Resonance ..	Flimsy partitions and linings	Adopt rigid construction, with studs, etc., at irregular spacings	
Masking noise ..	Insufficient sound insulation, bad-fitting doors and windows or badly designed vents	Select construction having insulation-value of at least 50 decibels	

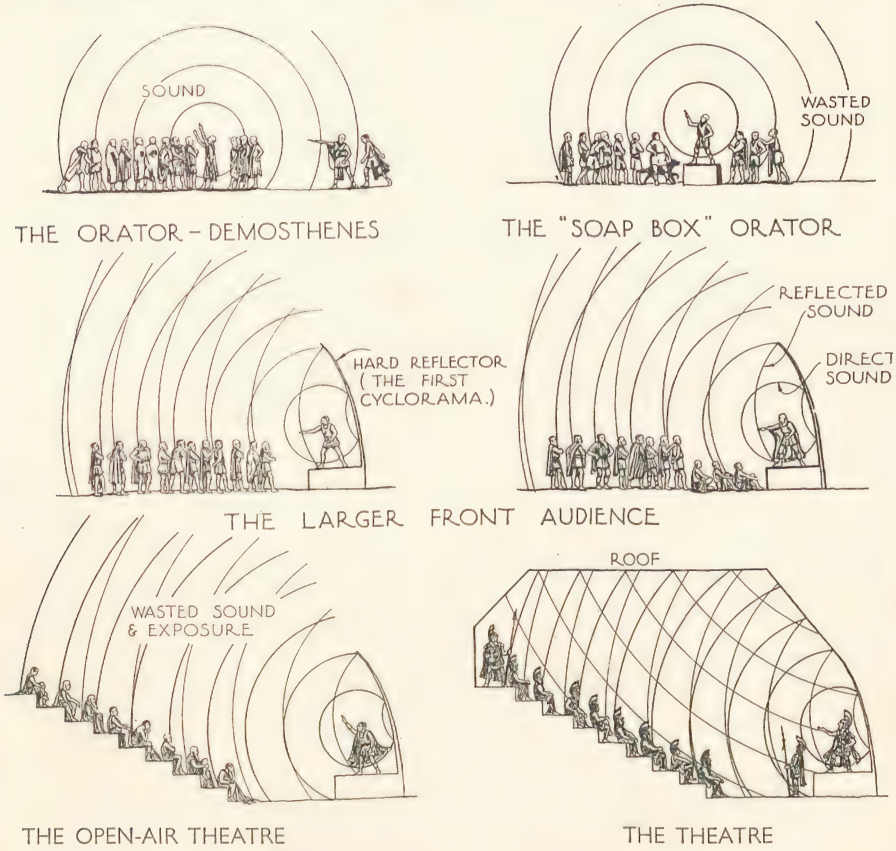


Fig. 3A.—THE EVOLUTION OF THE THEATRE
Illustrating the development of acoustical problems in buildings.

Reflecting Characteristics of Auditoria

The laws of reflection of sound in general conform to those of light, with the result that the angle of incidence equals the angle of reflection.

The acoustical image of a source of sound is therefore as far behind a reflecting surface as the origin is in front of it.

Upon this fundamental basis, the geometrical plotting of the reflecting characteristics of an interior can be worked out, a simple example being shown in Fig. 4.

The folded-paper method of investigation, shown in Fig. 5, will be found of use in checking the geometrical plotting.

By this method the complete wave-front is plotted by drawing a circle on tracing-paper, struck from the origin of the sound as centre, and the length of travel, corresponding to the time interval, as radius.

In the appropriate position the reflecting surfaces are also plotted,

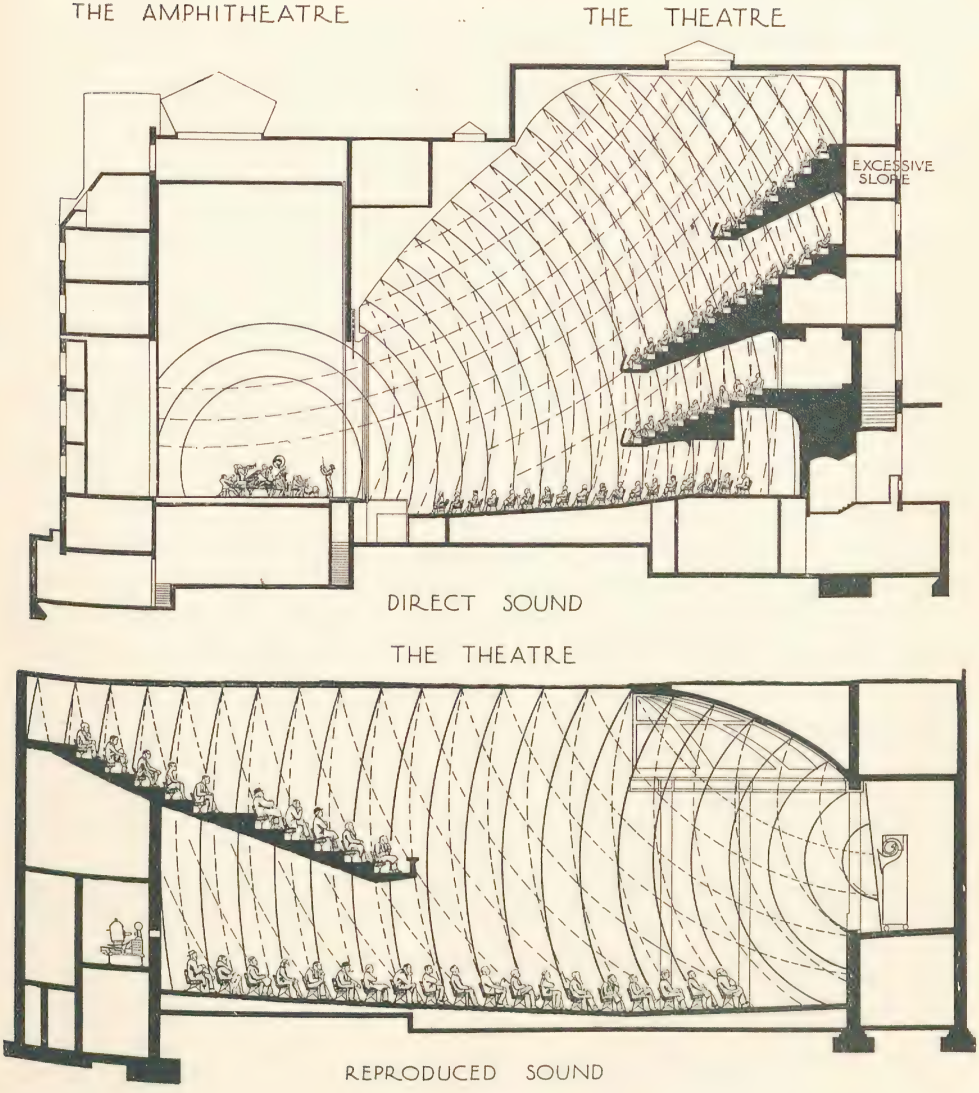


Fig. 3B.—THE EVOLUTION OF THE THEATRE

and the paper cut to the circumference of the circle and also along the chain-dotted lines.

If the circle of paper is then folded over at the reflecting surfaces, shown dotted on the illustration, the reflected wave-fronts, as shown by the geometrical plotting, will be clearly depicted.

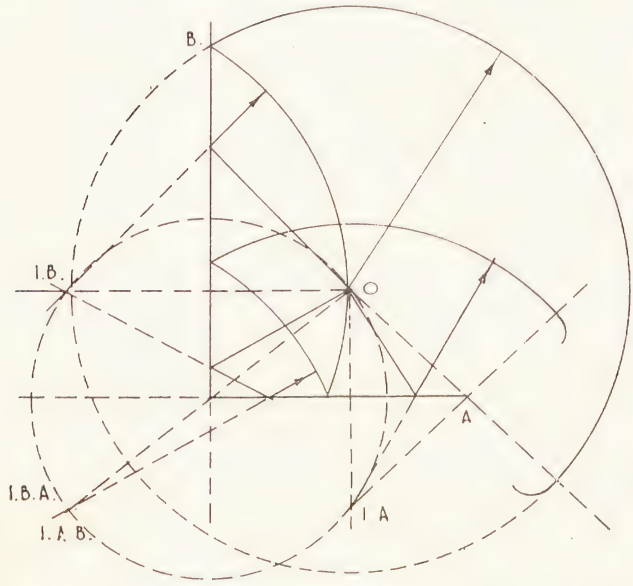


Fig. 4.—GEOMETRICAL PLOTTING OF REFLECTING CHARACTERISTICS OF AN INTERIOR

This method is particularly suitable in complicated interiors, and shows by the number of layers of paper at any point the relative instantaneous intensity of sounds at that point.

Shapes of Auditoria

It is desirable to keep all auditoria as small as practicable, the volume per seat of the audience being between 100 and 200 cu. ft.

Short broad halls are preferable to long narrow ones, and lofty ceilings are a disadvantage. The reflecting surfaces should be disposed near the origin at such angles as will bring the acoustic images near the origin. Floor and rear walls should be absorbent and, generally speaking, curvilinear interiors should be avoided, especially concave reflecting surfaces.

Fig. 6 gives reflecting characteristics of typical cross-sections of auditoria, types B and D being objectionable, unless the ceiling is made exceptionally absorbent to sound.

Control of Reverberation

In music the overlapping of sounds is not a serious objection—in some cases it may even be desired, especially when succeeding sounds are harmonious. Reverberation improves the sonority and impressiveness of slow and stately music, but is inclined to introduce a blurring effect in the rapidly moving passages.

In speech a limited amount of reverberation has a beneficial effect, but excessive reverberation causes a blurring and confusion of sounds.

It is not possible, except by the use of adjustable absorbents, to provide acoustical conditions which will be consistently satisfactory for the manifold uses to which an auditorium may be put, but as a rule the arrangement represents a compromise.

The preferred reverberation for rooms will depend entirely upon the use to which the room will be put. A music-room would require a different period from that of a board-room of the same size; in fact, it may generally be taken that for music a period 20 per cent. longer than that required for speech alone will give the best results.

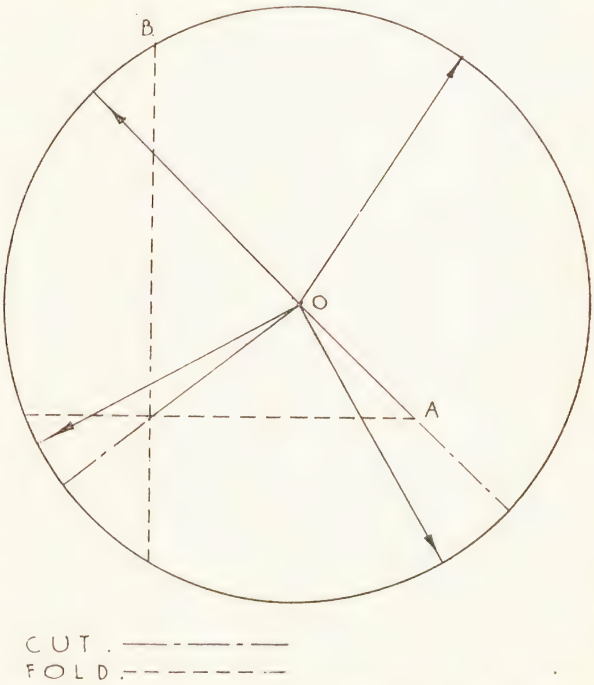


Fig. 5.—THE FOLDED-PAPER METHOD OF INVESTIGATING THE REFLECTING CHARACTERISTICS OF AN INTERIOR

Sabine, Watson, and Liftshitz have carried out independent and extensive investigations with the object of ascertaining the optimum reverberation in halls of various sizes for both speech and music, and the curves plotted in Fig. 7 are based upon investigations of a vast number of buildings considered highly satisfactory from an acoustic point of view, and represent the consensus of opinion in this respect. The periods are for C_4 (512 cycles per second).

(*a*) If the auditorium is to be used principally for direct choral music, add 40 per cent. to the time read off from the graph.

(*b*) If the auditorium is required mainly for direct orchestral music, add 15 per cent. to the time obtained from the figure.

(*c*) If the room is for unaided speech alone, deduct 15 per cent. from the reverberation given on the curve.

(*d*) If the auditorium is required for reproduced speech or music, deduct 15 per cent. from the appropriate reverberation time calculated as above under (*a*), (*b*), or (*c*).

Reverberation control may be effected by the adjustment of the acoustic absorption in a room brought about by the selection and use of sound-absorbing materials. A Table of the absorption coefficients of a number of materials is on page 155.

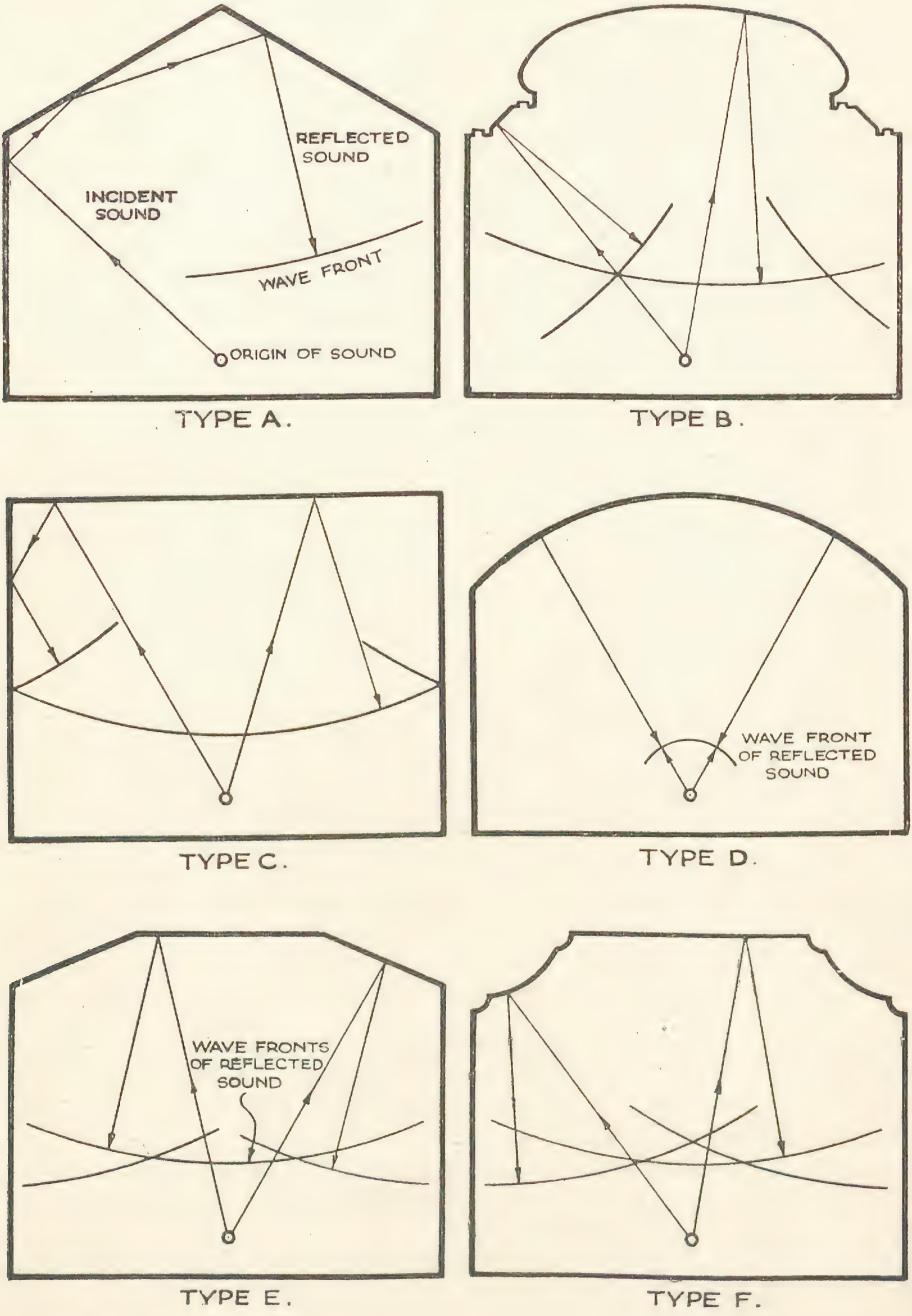


Fig. 6.—THE REFLECTING CHARACTERISTICS OF TYPICAL CROSS-SECTIONS OF AUDITORIA

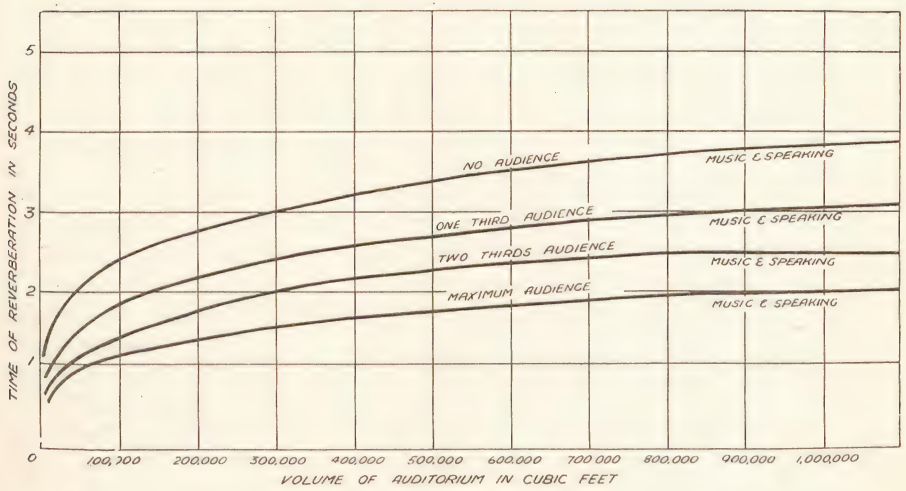


Fig. 7.—OPTIMUM REVERBERATION

SOUND-ABSORBING COEFFICIENTS FOR FREQUENCY 512

Materials	*Coefficients per sq. ft.*	*Materials*	*Coefficients per sq. ft.*
Open window as basis for comparison	1·00	Cork tile	0·03
Artificial acoustic stone	0·36	Curtains in heavy folds	0·40–0·75
Sound-absorbing plaster	0·14	Rock wool, bare	0·57
Balsam wool, bare, 1 in. thick, 0·26 lb. per sq. ft.	0·44	Glass (single thickness)	0·027
Brick wall	0·032	Hairfelt, bare, 1 in. thick, 0·75 lb. per sq. ft.	0·58
Brick wall, painted	0·017	Wood-fibre board, ½ in. thick	0·31
Brick, set in cement	0·025	Linoleum	0·03
Quilted eelgrass	0·51	Marble	0·01
Carpet, unlined	0·15	Plaster on wood lath	0·034
Carpet, lined	0·20	Plaster on metal lath	0·033
Carpet, with ½-in. hair felt	0·25	Plaster on tile	0·025
Carpet rugs	0·20	Acoustical plaster	0·21
Cane-fibre boards :		Stage openings, depending on stage furnishings	0·25–0·40
Type A, unpainted	0·25	2-in. straw partition board	0·36
Type B, painted or unpainted	0·47	Ventilators	0·75
Type BB, painted or unpainted	0·70	Wood, plain	0·06
Type C, painted or unpainted	0·30	Wood, varnished	0·05
Cork board :		Adult person, each	4·7
1 in. thick, 0·875 lb. per sq. ft.	0·30	Plain wood seats, each	0·15
Sprayed with cold-water paint	0·30	Church pews, per seat	0·2 –0·5
2 in. thick, 1·6 lb. per sq. ft.	0·35	Seats, upholstered seat and back	0·75–2·00
		Seat cushions, per seat	1·00–2·00

W. C. Sabine Formula

The reverberation time is specifically defined as the time required for the steady-state energy density in an enclosure to decay to

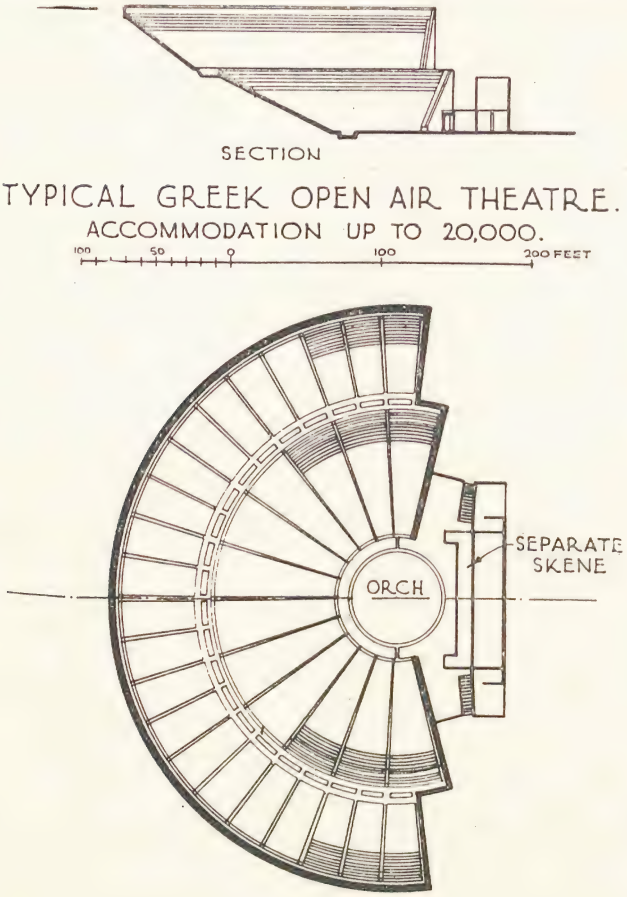


Fig. 8.—TYPICAL GREEK THEATRE

one-millionth of its value when the source is cut off, i.e. equivalent to 60 db. drop in loudness.

On this basis, W. C. Sabine showed that the reverberation time t in seconds in an enclosed space equals one-twentieth part of the volume in cubic feet divided by the total absorption present in "open-window units."

$$t = \frac{0{\cdot}05\mathrm{V}}{a\mathrm{S}_t} = \frac{\mathrm{V}}{20\mathrm{A}}$$

where V is the volume in cubic feet, a is the average coefficient of absorption, and S_t the total surface exposed to the impact of the sound waves.

The formula may be written—

$$t = \frac{\mathrm{V}}{20\ (\mathrm{S}_1 a_1 + \mathrm{S}_2 a_2 + \mathrm{S}_3 a_3 + \ldots.)}$$

where a_1, a_2, a_3 .... are the respective sound-absorbing coefficients of the various materials having surface of S_1, S_2, S_3, etc.

The method of calculating the total absorption present in "open-window units" may be seen from the following example:—

Example

Acoustic analysis of an auditorium to accommodate 1,000 persons (for direct music and speech).

Volume preferred for audience of 1,000 = 1,000 × 200 = 200,000 cu. ft.

Actual volume provided by design = 209,000 cu. ft.

From the curve, we see that the optimum reverberation period for one-third audience should be 2·2 sec., whence from Sabine's formula we see that the total absorption should be—

$$\frac{0{\cdot}05 \times 209{,}000}{2{\cdot}2}$$

= 4,750 units

The actual absorption provided is as below :—

	Units
Plaster on tile, 6,400 sq. ft. at 0·025	= 160
Wood, polished, 20,000 sq. ft. at 0·04	= 800
Concrete covered with marble, 8,000 sq. ft. at 0·01	= 80
Absorbent fibre board, 3,000 sq. ft. at 0·31	= 930
Curtains, 400 sq. ft. at 0·40	= 160
Seats, 1,000 at 1·0	= 1,000
Total permanent absorption	= 3,130
Add one-third audience, 333 at 3·7	= 1,232
(Note seat occupied already taken as 1·00.)	
Total	= 4,362

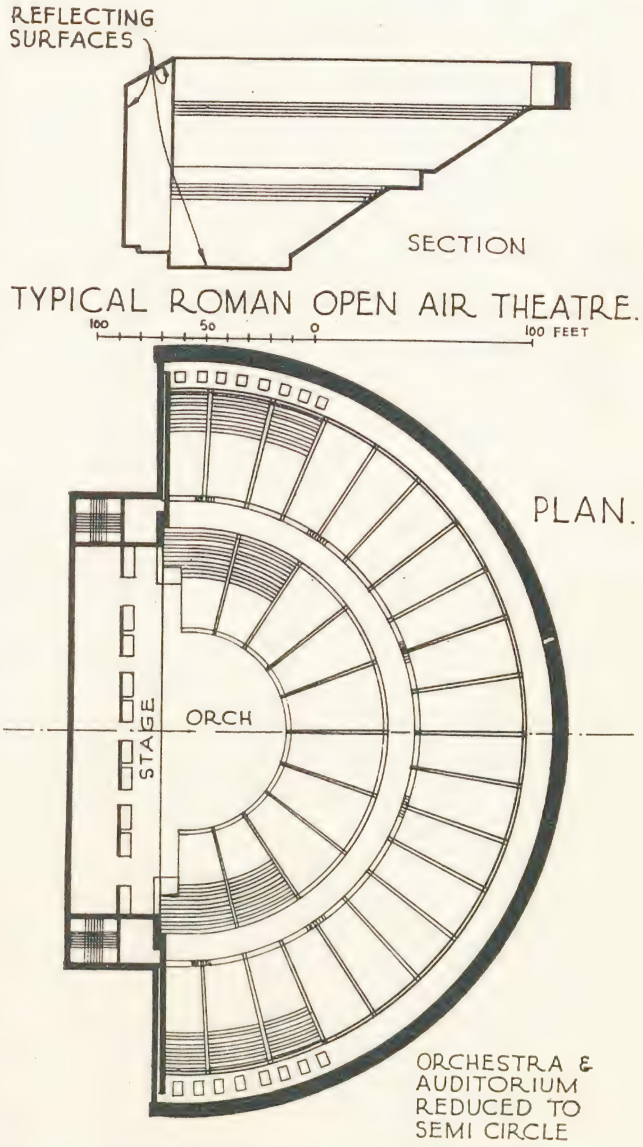


Fig. 9.—TYPICAL ROMAN THEATRE

Leaving 4,750 — 4,362 = 388 absorption units to be provided by additional absorbents. If unlined carpets placed on the marble floor be used for this purpose, the coefficient would be 0·15 — 0·01 = 0·14, and—

$$\frac{388}{0{\cdot}14} = 2{,}771 \text{ sq. ft. would be required.}$$

Fig. 10.—THEATRE IN NEW DE LA WARR PAVILION, BEXHILL

An even distribution of sound throughout the auditorium is obtained by the special reflectant ceiling and sound board over forestage. This acoustic ceiling and proscenium in hard fibrous plaster are white, framed in a continuous metal tube. The absorbent walls above stalls level are natural-colour acoustic board. (*Architects: Erich Mendelsohn & Serge Chermayeff, F.R.I.B.A.*)

The auditorium would then give optimum reverberation at one-third audience, and the acoustics should be good from this point of view.

The actual units of absorption in the proposed building are calculated as indicated above, and these, subtracted from the ideal total absorption, give the number of units to be provided in additional absorbent materials.

A later section deals with the acoustical design of buildings.

QUESTIONS AND ANSWERS

What are the three principal characteristics of Sound ?

(1) Pitch.
(2) Loudness.
(3) Tone quality.

What are the general requirements for good Acoustics in Buildings ?

(1) Uniform distribution of sound throughout the room, without distortion.
(2) Proper reverberation time.
(3) Adequate loudness of sound throughout the room.
(4) Absence of disturbing extraneous noise.

What is meant by Reverberation Time ?

The time required for the steady-state energy density in an enclosure to decay to one-millionth of its value when the source is cut off. Its value in seconds in an enclosed space equals one-twentieth part of the volume in cubic feet divided by the total absorption present.

What unit is used for measuring Sound Absorption ?

The "open-window unit." One square foot of an open window is reckoned as having a sound-absorbing coefficient of 1 (for frequency 512). This serves as a basis of comparison with materials used in the building, furnishings, etc.

How is the required Reverberation Time ascertained for any particular hall ?

It is ascertained by referring to data supplied on the basis of investigations carried out by Sabine, Watson, and Liftshitz on a vast number of buildings considered highly satisfactory from an acoustic point of view. Curves are based on this data and represent the consensus of opinion in this respect.

How is the Absorption present calculated ?

The total absorption is represented by the formula $S_1 a_1 + S_2 a_2 + S_3 a_3 + \ldots$., where a_1, a_2, a_3, ... are the respective sound-absorbing coefficients of the various materials exposed to the impact of the sound waves, and S_1, S_2, S_3, etc., the surface areas of the materials in square feet.

What allowance should be made for Sound Absorption by the Persons in the Audience ?

For each adult person a sound-absorbing coefficient of 4·7 is allowed (for frequency 512). The coefficient for the seats should be subtracted from this value, and the result multiplied by the number of persons in the audience. This product is added to the total amount calculated for the permanent absorption provided by the various sound-absorbing materials.

What are the desirable Limits of Size of Auditoria ?

Between 100 and 200 cu. ft. of volume per seat of the audience.

How is Reverberation Control effected ?

By the adjustment of the acoustic absorption in a room, brought about by the selection and use of sound-absorbing materials.

What is the procedure for checking the measure of Reverberation Control ?

By the use of Sabine's formula. Thus, the total absorption should be :—

$$\frac{0{\cdot}05\ \mathrm{V}}{t}$$

where t is the optimum reverberation period, and V is the volume of the auditorium in cubic feet. The value of t is obtained from the graphs available, based on the suitable volume of the auditorium, allowance being made according to the purpose for which the auditorium is to be used, i.e. speech, music, etc. The actual absorption provided can then be calculated, and the two totals compared.

THE ACOUSTICAL DESIGN OF BUILDINGS

THE following article gives data on applying the acoustical principles described in the previous article to various types of buildings and structures.

Open-air Theatres

In still, open air the unaided voice can be heard and understood a distance of 90 ft. in front, 75 ft. on each side, and 30 ft. behind the speaker.

The modern open-air theatre should follow the Greek or Roman tradition (see pages 156 and 157), the orchestra being retained as a paved area for the reinforcement of sound by reflection, the splayed walls and sloping roof over the stage being also indispensable in this connection.

Bandstands

The acoustic principles of design of open-air bandstands may be summarised as below :—

(1) The natural acoustic characteristics of the site should be studied, and the bandstand designed to suit.

(2) The platform should be of timber, specially stressed in construction to make it a loud resonator.

(3) The ceiling should be a hard reflector, so shaped as to throw strong reflections downwards and outwards to the audience.

(4) There should be a hard, reflecting, paved area adjacent to the platform, kept clear of chairs, etc., to brighten the tone.

Buildings for Speaking-voice Conditions

The preferred reverberation periods for speech alone are obtained by deducting 15 per cent. from the periods given in Fig. 7, page 155, and the desirable volumes per seat of audience should range from 75 cu. ft. per person in a 250-seat auditorium to 120 cu. ft. per person in a 4,000-seat auditorium.

For lecture theatres and council chambers, in which a tribune position is used for the speaker, a suitable arrangement is shown in Fig. 1, and the following points should be complied with :—

(1) The reverberation should be less than $1\frac{1}{2}$ sec.

(2) The volume per person, 100–150 cu. ft.

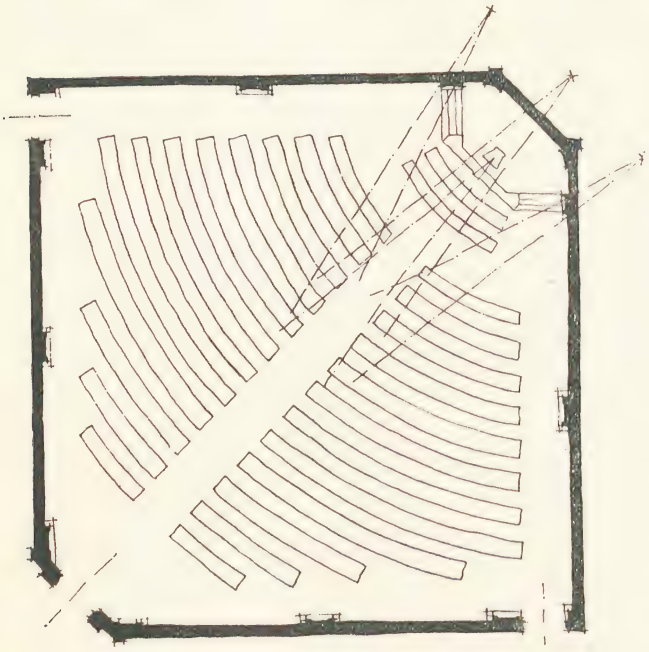


Fig. 1.—LECTURE THEATRE

(3) Hard, reflecting surfaces should be disposed about the position of the speaker, and so inclined as to keep the acoustic images as close to the source as possible.

(4) The seating should be highly absorbent.

(5) Rear walls should be absorbent.

(6) Reflecting surfaces should be hard and polished in order to maintain brightness of tone and intelligibility of speech.

In buildings for debate, when the house may be addressed from any seat on the floor, the following points should be complied with :—

(*a*) The ceiling should not be more than 30 ft. above the seating area.

(*b*) Walls and floor should be absorbent.

(*c*) Conditions 1, 2, 4, and 6 enumerated above should also be applied to this special type of building.

Concert Halls

Concert halls should comply with conditions for direct sound, as set out in Fig. 7, page 155, and the volume per seat should range from 150 cu. ft. per person in a 250-seat auditorium to 200 cu. ft. per person in a 4,000-seat auditorium.

Fan shapes and oblong plans are best.

Hard, polished reflectors should be disposed about the platform, to preserve brightness of tone. Distant surfaces should be absorbent, the ceiling preferably flat and reflecting. The floor and seating area highly absorbent. The platform and orchestra and adjoining side walls should be polished and resonating.

Reflections back to the platform must be avoided by breaking up the surface of the back wall or the front of the balcony, and/or by using absorbents.

The Opera House

In the opera house, music is of primary importance, and special attention must be paid to the production of good tone.

The building should comply with the conditions intermediate between those set out for direct choral and orchestral music on the curves in Fig. 7, page 155.

The volume per seat should range from 225 cu. ft. per person in a 250-seat auditorium to 300 cu. ft. per person in a 4,000-seat auditorium.

The auditorium should preferably be fan-shaped, with resonating splay walls and reflecting splay ceiling to the proscenium opening.

The reflecting surfaces should be near the stage, and the absorbents remote.

The ceiling sloping upwards from the proscenium should be an acoustic mirror, and curvilinear shapes, except coves to ceilings at rear walls under balconies, should be studiously avoided.

The stage house should be reflecting, especially the back wall, which should preferably be of glazed brick.

The stage, apron, orchestra pit, and lower panels of the proscenium should be framed together in polished and resonating wood.

The floor and seating area should be highly absorbent, but the floor of the orchestra pit should be hard and reflecting.

The Theatre

The theatre should be designed for the acoustical conditions recommended for opera houses, except that the reverberation should be less, and the curves for direct music and speech used as set out in Fig. 7, page 155, and the ceiling underneath the balcony coved to reinforce the sound in the back seats.

Curved ceilings are dangerous unless the radius of curvature is at least twice the height of the auditorium.

The Cinema

The acoustic requirements of the cinema are the same as those for the theatre, except :—

(1) The reverberation and volume per seat should be adjusted for reproduced music and speech.

(2) Provision has usually to be made for an organ in addition to an orchestra.

(3) A fan shape with the throat at the picture is quite suitable.

(4) All seats should be highly absorbent.

Churches

Churches should be designed for choral music, page 153, but for direct speech in sermons from the pulpit, or reading from the lectern, hard, reflecting, sounding boards over the speaker will be found effective in

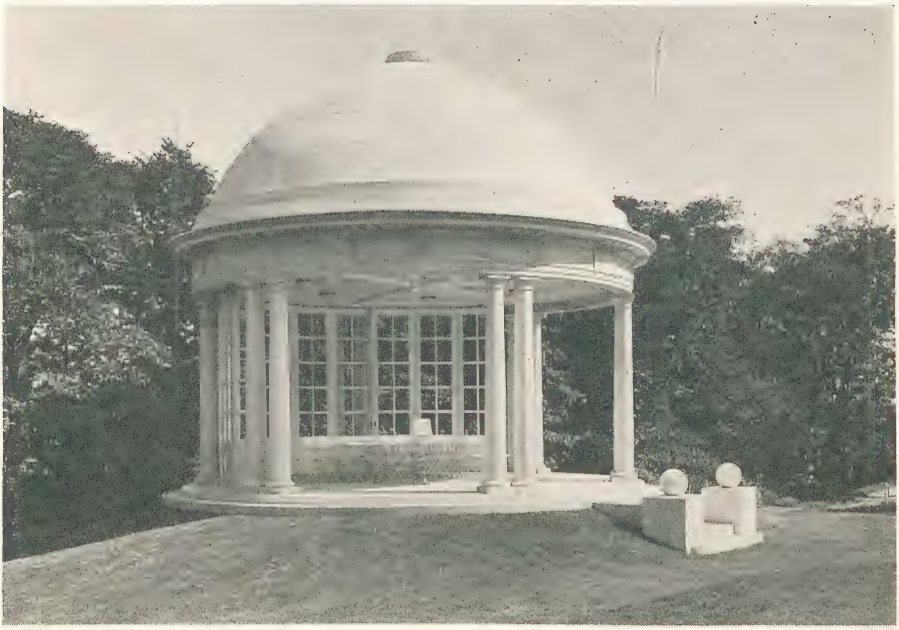


Fig. 2.—BANDSTAND, VALE PARK, WALLASEY

A flat wooden ceiling at the frieze level is provided, divided into six segments by moulded ribs. A sliding glass screen is provided which is capable of enclosing half the bandstand. It has the dual purpose of a wind screen and sound projector. The screen may be moved to any position, the ceiling and floor tracks forming complete circles. (*Architect: Mr. L. St. G. Wilkinson, M.Inst.C.E., Borough Engineer and Surveyor.*)

screening the speech from the lofty ceiling and also in throwing forward and downward to the congregation a strong reinforcement of sound.

The volume per person may be as much as 700 cu. ft. in large churches, and the reverberation over 7 sec., even with a large congregation present.

The design of a church should be kept into one cell, as far as possible without transepts.

Recording Studios for Sound Films

Recording studios for sound films should generally be of rectangular shape, the size found most suitable under modern conditions being 120 ft. long by 80 ft. wide by 35 ft. high to flat ceiling.

Diffusion of sound in the studio can best be ensured by the use of absorbents of different characteristics in alternate vertical strips (about 3 ft. wide) on the walls and ceilings, or preferably by the use of an independently supported and corrugated lining.

If the studio has a period of less than 1 sec. when empty, satisfactory results can be obtained by the use of reflectors, resonators, and absorbers on the "sets" constructed therein.

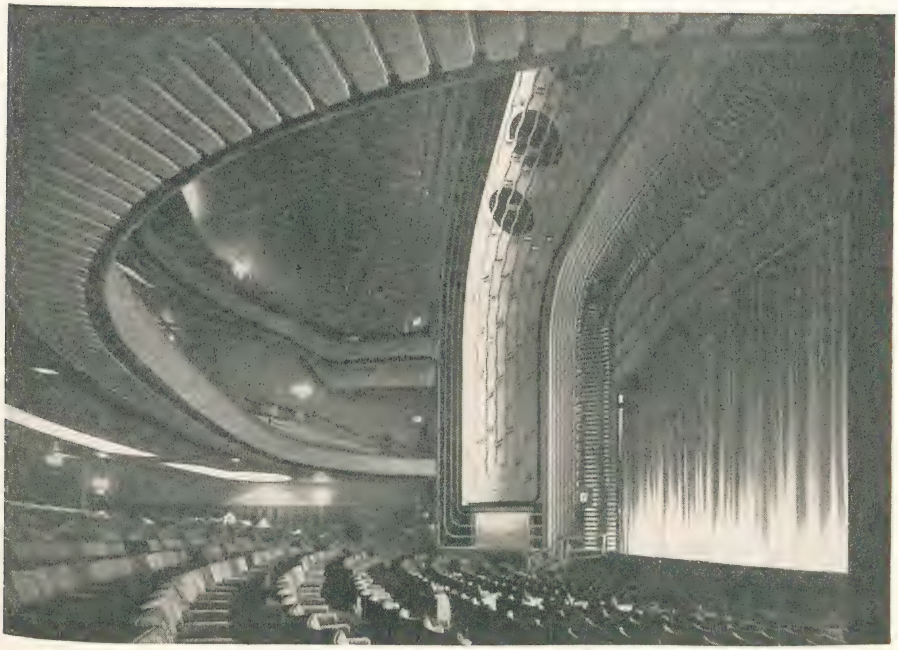


Fig. 3.—NEW THEATRE, OXFORD
The ceiling is carefully calculated to act as an acoustical reflector, and acoustical correction was introduced in consultation with Mr. Hope Bagenal. (*Architects: W. & T. R. Milburn, FF.R.I.B.A.*)

Monitoring Room

The acoustic condition of the monitor room (in which the sound being recorded is played over through an amplifier-loud-speaker system) should therefore approximate to that of the theatre, and a reverberation period of 1½ sec. is recommended, with a distribution of reflectors, resonators, and absorbents simulating the arrangement of the theatre auditorium.

Review Theatres

In the sound-film studio assembly, a small theatre is used for review and editing purposes, and the period therein should be between 1½ sec. and 2 sec. ; reflecting, resonating, and absorbing surfaces being disposed as recommended for the cinema.

Play-back Studio

In the play-back studio—used, as its name suggests, for synchronisation of sound to "mute" sequences, or any of the many "dubbing" processes in connection with the adjustment of sound records in sound-film work—adjustable absorbents will be necessary to enable the period to be changed from ½ sec. to 2 sec. according to requirements.

Gramophone Recording Studios

The gramophone recording studio should have a reverberation adjustable between the limits of $\frac{1}{2}$ sec. and $2\frac{1}{2}$ sec.

For records for the home, recorded reverberation times as below are suitable :—

Speech according to type	intimate	0·5 sec.
	sermon	1·0 „
Instrumental solos		0·8 „
Solo vocalist		1·0 „
Trios to octets		1·0–1·8 „
Orchestra		1·5–2·5 „
Full bands		4·0 „

Audition Rooms

For piano and gramophone record music in audition rooms, a reverberation of 1 sec. at C_4 appears to give best results.

Noise Abatement

Noise is best reduced by suppression at the source, but if this is not entirely possible, noise can be abated by acoustical treatment of the surroundings.

The amount of reduction of noise in db. by the installation of sound absorbents can be calculated from the absorption ratio :—

$$\frac{\text{The absorption present after the treatment}}{\text{The absorption present originally}}$$

and read off from the following table :—

Absorption Ratio	*db. Reduction in Noise*
1	0
2	3
3	4·7
4	6
5	7
6	8
7	8·5
8	9

In practice it is sufficient to attempt no more than a 7-db. reduction in loudness by the introduction of absorption. Such a reduction causes a very appreciable reduction in the annoyance of noise—an amount which, in the opinion of average individuals, is as much as 50 per cent. or 60 per cent.

SHORING

WHEN extensive alterations are necessary, a building may have to be temporarily supported by means of " shores." The three types usually employed are termed " dead shores," " flying shores," and " raking shores." A " dead shore " actually supports the " dead weight " of the wall. A " flying shore " is horizontal, and incapable of taking any vertical load, its function being to keep the wall plumb. A " raking shore " is something between the two. It supports the wall to a certain extent, and also imposes a horizontal thrust to keep it upright.

Stability of Walls

A wall is stable so long as its centre of gravity falls inside the " middle third " of its base. Fig. 1 shows a wall leaning slightly but still stable. It may not require " shoring up " to prevent its falling, but it does require support to prevent it going further off the plumb. Suppose that further subsidence of the foundation takes place, and, being a boundary wall, it is exposed to the force of the wind ; a certain amount of force would be thrown against the " shore." If the " shore " consisted of a single " raker " set at an angle of 45°, it would press vertically and horizontally an equal amount. If the combined weight of the leaning wall and the wind-pressure amounted to, say, 1,000 lb., then the weight of the material above the wall piece must be at least 500 lb. ; otherwise it would be lifted, and collapse would follow.

Types of Shores

Diagrams of shores are shown in Fig. 2.

Dead Shore

In the case of the " dead shore," buckling might be said to be the principal danger ; therefore the thickness of the support must be in proportion to the length, to give the necessary stiffness. The support will buckle on the thinnest way of the timber, so " die-square " timbers are best. A 6-in. by 6-in. " dead shore " would stand up to its load better than a 12-in. by 3-in. although their respective cross-areas are the same. The latter would be liable to buckle on its 3-in. side.

Flying Shore

In " flying shores," " wracking " might be termed the danger to be guarded against. A triangle cannot change in shape if the three sides

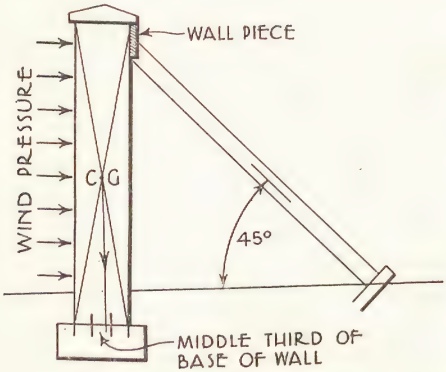


Fig. 1.—A RAKING SHORE

A wall is stable so long as its centre of gravity falls inside the "middle third" of its base.

remain unaltered in length. The triangle ABC, Fig. 2, is made up of part of the horizontal member AC, half the wall piece BC, and the brace AB. The "needle" at B prevents the point of the brace from moving upwards, the straining-piece keeps A in position, and the distance BC is constant between the mortices in the wall piece. If the joints are properly constructed, the triangle ABC, and the other triangles making up the whole "shore," remain unaltered in shape, therefore "wracking" is avoided.

Raking Shore

In dealing with the example shown in Fig. 1 it was stated that the "raking shore" pressed vertically and horizontally an equal amount. The thrust along the line of the "raker" is split up into vertical and horizontal components. Therefore it follows that to support a vertical load a "raking shore" is less effective than a "dead shore." Neither would it be as good as a "flying shore" to counteract horizontal pressure, but it is the type of shore used for walls fronting on a street. A solid bearing at D, to guard against subsidence (as suggested in Fig. 2 at D), and joints properly fitted are essential.

Load on Dead Shores

Before calculating the size of the "needle" necessary to carry the weight of the portion of the wall shown in Fig. 3, it would be advisable to study Fig. 4. A piece of yellow deal 1 in. by 1 in., laid on supports 1 ft. apart, will break when a weight of about 4 cwt. is placed at the centre. Take now a piece of 1 in. by 2 in. (*b*); being double the breadth it will carry double the load, viz. 8 cwt. So "the load varies directly as the breadth." Turn the piece of 1 in. by 2 in. on edge, as at (*c*), and it will take a load of 16 cwt. to break it. Compare (*c*) with (*a*): the depth is doubled but the load is squared: $4 \times 4 = 16$ cwt. So "the load increases directly as the square of the depth." Refer to (*d*): where the span is doubled it will take only 2 cwt. to break it. So "the load varies inversely as the span." At (*e*) the 2 ft. span is retained, but the piece is increased to 2 in. by 1 in. on edge. Work this out by the formula $BW = \frac{Cbd^2}{L}$, where BW stands for breaking-weight in cwt., C = constant, b = breadth of beam in inches, d = depth of beam in inches, L = length of span in

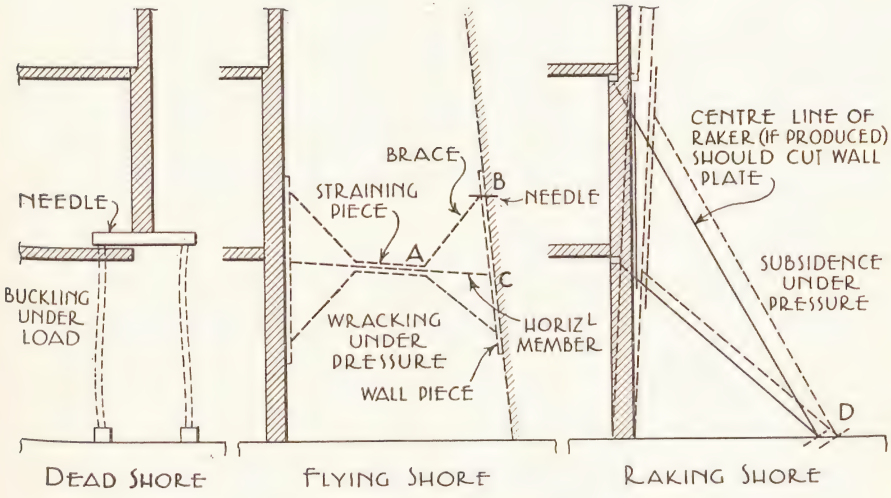


Fig. 2.—THREE EXAMPLES OF SHORES

A dead shore actually supports the dead weight of the wall ; a flying shore is horizontal and incapable of taking any vertical load ; and a raking shore is something between the two.

feet. $BW = \frac{4 \times 1 \times 4}{2} = 8$ cwt., so the " beam " at (*e*) will break under a load of 8 cwt.

Simple Experiment

To appreciate this, take a piece of yellow deal 1 in. by 1 in. and lay it on bricks 2 ft. apart. It should take a man of 16 stone to break it when he puts his weight at the centre. This would not be an accurate test from a theoretical point of view because the load is not concentrated on a " point " at the centre, but in practice similar conditions occur. In the example shown in Fig. 3 the load is distributed over the thickness of the wall. Timber, being one of Nature's products, may vary with every specimen tested, but 4 cwt. is found to be the average weight under which a sound specimen of yellow deal will break when tested as shown at (*a*) Fig. 4. This 4 is then called a " constant," C in the formula. For Douglas fir and pitch-pine this " constant " might be 4·5 or 5, on account of their greater transverse strength.

Factor of Safety

As stated, specimens of the same kind of timber vary, so to allow for this " a factor of safety " is adopted. If an actual load of 140 cwt. has to be carried, this load is multiplied by 4 (factor of safety), and the beam is assumed to be carrying $140 \times 4 = 560$ cwt.

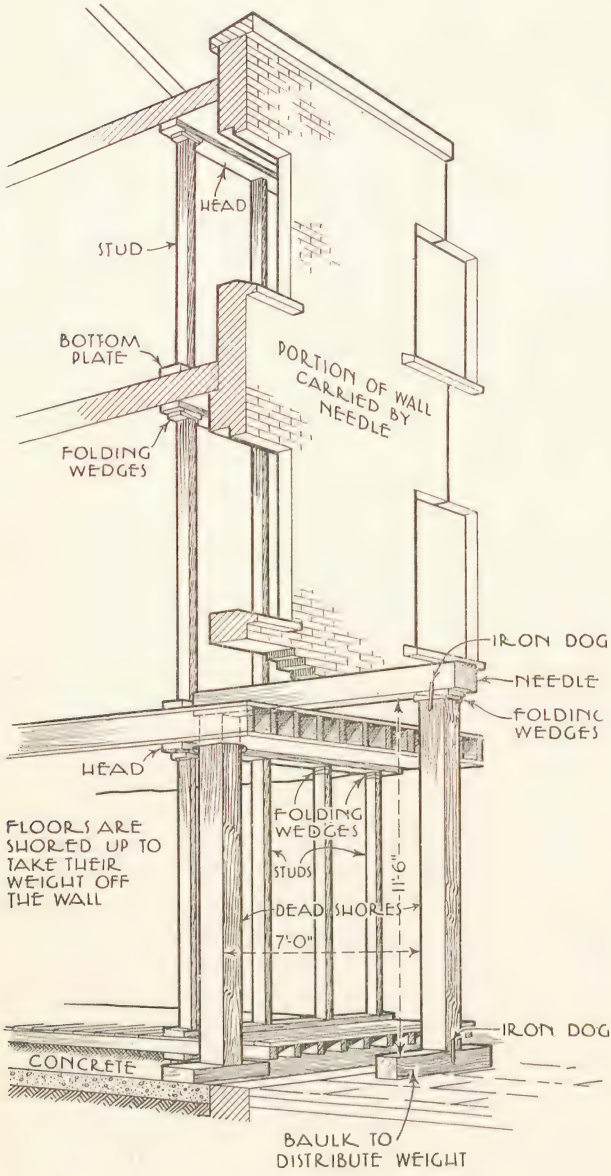


Fig. 3.—A DEAD SHORE
Showing load distributed over the thickness of the wall.

Calculation for Size of Needle

The "needle" in Fig. 3 carries a load of approximately 140 cwt. The "needle" is subjected to this load at the centre of the 7-ft. span. But the "needle" must be strong enough to carry four times this load, viz. 140 × 4 (factor of safety) = 560 cwt. Now BW $= \frac{Cbd^2}{L}$. Try how a 9-in. by 9-in. "needle" will stand the load :–

$$BW = \frac{4 \times 9 \times 81}{7}$$

$$= 416{\cdot}6 \text{ cwt.}$$

This is on the small side. Try 10 in. by 10 in. :

$$BW = \frac{4 \times 10 \times 100}{7}$$

$$= 571{\cdot}4 \text{ cwt.}$$

So a 10-in. by 10-in. needle should be used.

Table showing the "safe" concentrated loads at the centre of a yellow deal beam in cwt. is on page 171.

Proportion for Dead Shore

The shores supporting the "needle" should not be more than twenty times their least dimension. For instance, in Fig. 3 the shore is approximately 11 ft. 6 in. long ; therefore if "die-square" stuff is used it should

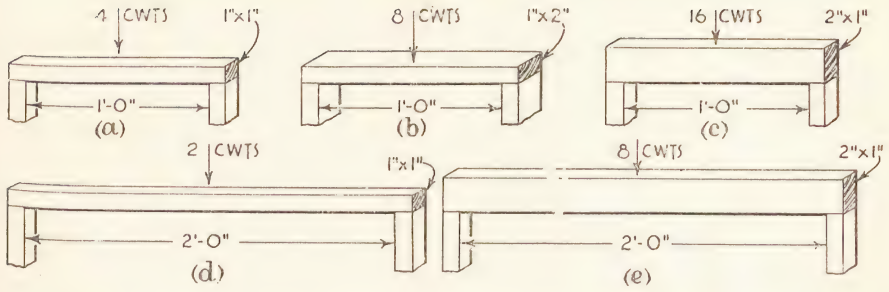


Fig. 4.—DIAGRAM SHOWING LOADS ON DIFFERENT TYPES OF SHORES

be at least 7 in. by 7 in. As the "needle" is 10 in. by 10 in. it would be more practical to use a 10 in. by 7 in., in order to have a full bearing at the top.

Size of Beam in Inches	*Span of Beam in Feet*				
	7	8	9	10	12
7 × 7 .	196·0	175·5	152·4	137·2	114·3
8 × 8 .	292·6	256·0	227·6	204·8	170·7
9 × 9 .	416·6	364·5	324·0	291·6	243·0
10 × 10 .	571·4	500·0	444·4	400·0	333·3
12 × 12 .	987·4	864·0	768·0	691·2	576·0

Note.—If the beam is subjected to a uniformly distributed load it will carry twice the weight given in the table.

A safe working stress on the end grain of yellow deal is about 900 lb. per square inch. It may often happen that the ends of a dead shore are not compressed to this extent by the load which it carries, yet it would not be advisable to reduce it in size. As stated under Dead Shore (see Fig. 2), it is buckling which is the principal danger. The following table gives the minimum dimensions for dead shores as used in Fig. 3:—

Length of Shore in feet	10	12	14	16
Dimensions in inches	6 × 6	7 × 7	8 × 8	10 × 10

Shores over 16 ft. should be braced, even if their dimensions are in the same ratio to their length as those given in the above table.

Erection

For "dead shores" see Figs. 3 and 8; before the building is disturbed all floors should be supported from base to roof, to

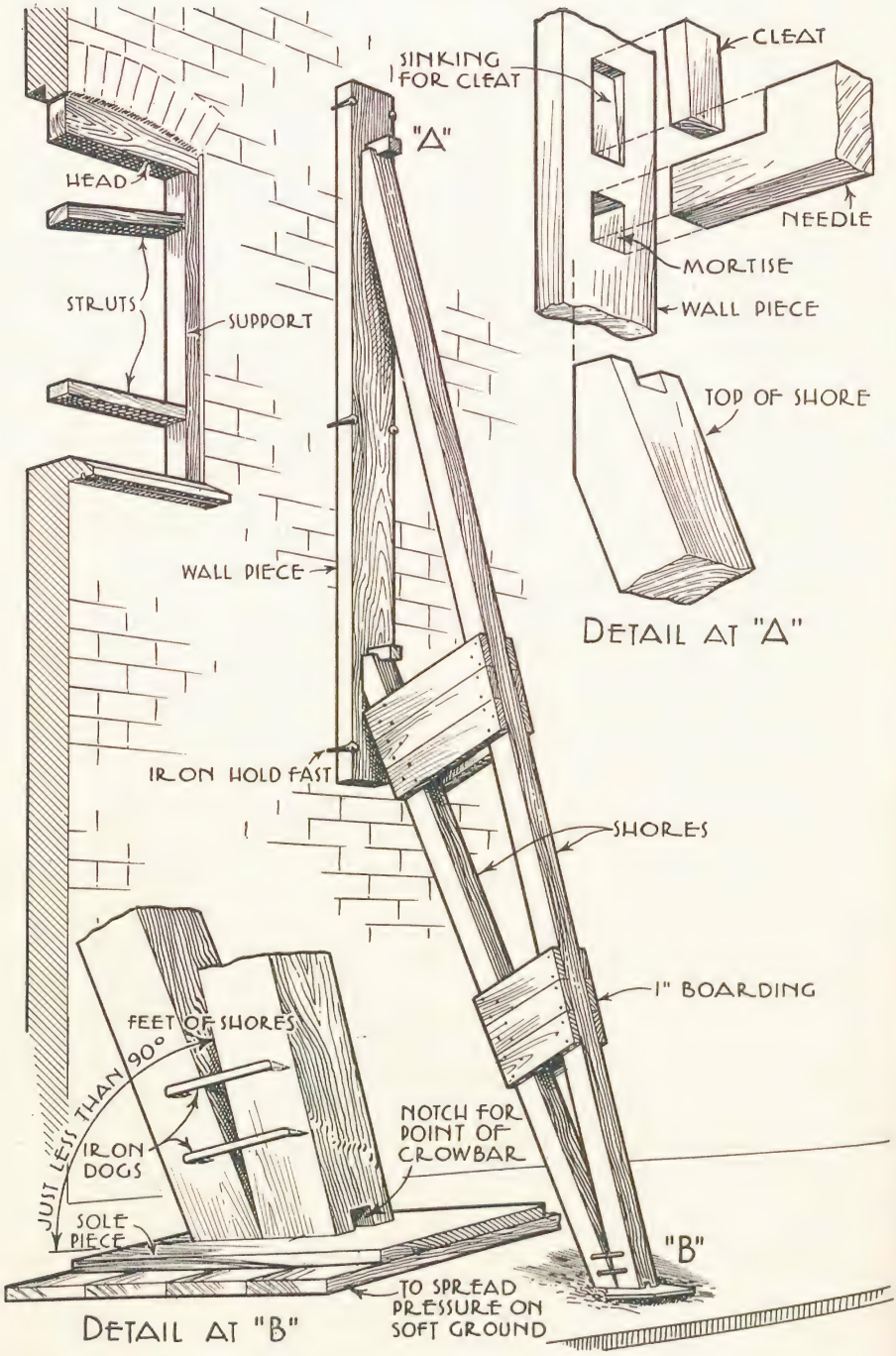


Fig. 5.—A TWO-RAKER BATTERY

take their weight off the wall. Holes for the "needles" are then "punched" through the walls, balks laid in position to spread the weight, uprights erected and tightened by folding wedges at the top. Wrought-iron "dogs" are then driven to prevent movement at top and bottom; the wall under the needles may now be removed.

Raking Shores

In Figs. 5, 6, and 8 raking shores of different types are shown. Fig. 5 shows a "two-raker battery." "Headers" are cut out near where the top and bottom of the wall piece will come. Mortices are made in the wall piece to coincide with the holes cut in the brickwork, and the wall piece fixed in position with "hold-fasts." A sole piece is then bedded as shown, the needles and cleats fixed in the mortices, the rakers fitted, hoisted, and levered tightly under the "needle" by a crowbar. One-inch boarding is nailed across as shown. This has the effect of stiffening the "battery" against vibration, and making the "rakers" react in unison. A "four-shore battery" is shown in Fig. 6. Difficulty in obtaining the "top raker" in one length is overcome by one or other of the methods shown.

Size of Rakers

The length of "rakers" governs their dimensions. The table on page 175 is a guide to the number of rakers required to suit the height of the wall. Their dimensions are given in inches.

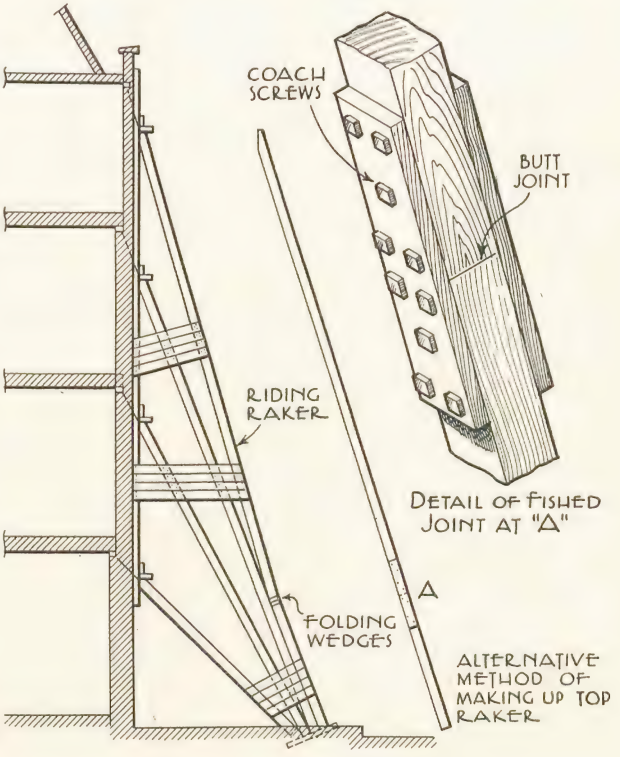


Fig. 6.—A FOUR-SHORE BATTERY

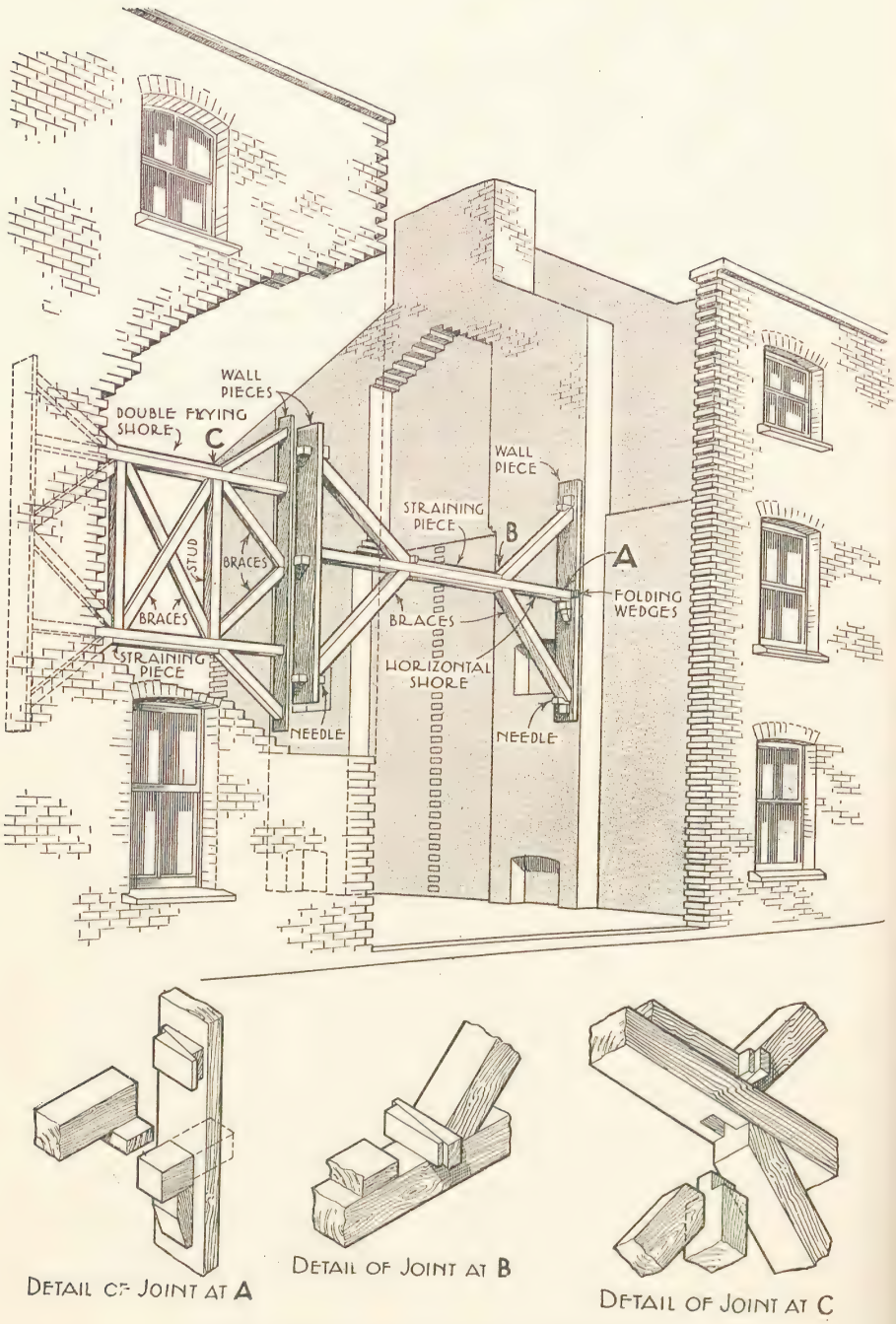


Fig. 7.—SINGLE AND DOUBLE FLYING SHORES

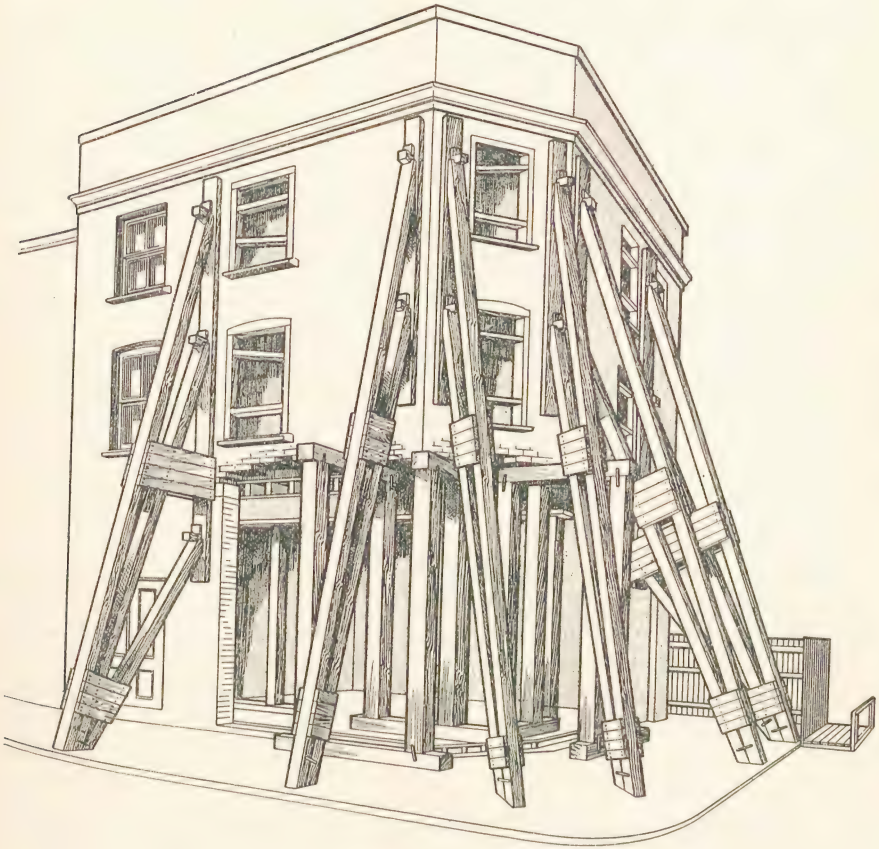


Fig. 8.—SHORING FOR CONVERSION OF HOUSE TO SHOP

NUMBER OF RAKERS REQUIRED

Height of Wall	*Number of Rakers*	*Dimensions of Rakers in inches*
Up to 20 ft. . . .	1 or 2	5 × 5
20–30 ft. . . .	2	6 × 6
30–35 ft. . . .	3	7 × 7
35–40 ft. . . .	3	8 × 8
40–50 ft. . . .	4	9 × 9

Flying Shores

When a building has to be entirely demolished, as suggested in Fig. 7, the party walls of the adjoining property will have to be supported. If

these walls are not too far apart " flying shores " are erected as shown in Fig. 7. " Single " and " double flying shores " are shown. It will depend on the condition and height of the walls as to which of these shall be used. The position of the " shores " will depend on the arrangement of the new premises ; but they must be so placed that permanent support is given by the new walls before they have to be dismantled. Their erection up to a certain point follows that for " raking shores," i.e. " wall pieces," " needles," and " cleats " are fixed, then the " horizontal shore " is laid on the " needle " (see detail at joint A), and the folding wedges tightened. The under braces and " straining-piece " are fitted as tightly as possible to remove any " sag " of the " horizontal shore." If a slight " camber " can be induced, so much the better. When the top braces and top straining-piece are in position, and the folding wedges tightened (detail at joint B), the whole framework will be tightened up, tending to make the " horizontal shore " sag ; hence the precaution when fixing the braces underneath.

Conversion of House to Shop

In a flat wall, where the shop front is a matter of from 12 to 15 ft. long, " dead shores " alone may be used to take the weight of the brickwork over ; but for longer stretches, or at a corner as shown in Fig. 8, " raking shores " should also be employed. In addition to the preliminaries stated under *Erection* all window sashes should be removed, and window openings firmly strutted as shown to keep the structure as rigid as possible.

Hoardings

When shores or hoardings encroach on the public way a licence for their erection must be obtained. A portion of a hoarding, with temporary footway and guard rail, is shown in Fig. 8. Their construction does not require explanation. They must be made safe for pedestrians, and should not impede the flow of storm water in the gutter. Where road gullies occur, suitable access to these should be provided.

BRICKWORK

PART II.—WALL FINISHES, CHIMNEYS, ETC.

BUILDINGS with basements must be so constructed as to resist the percolation of water or dampness through the walls and floors. The locality in which the building is to be erected solely governs the choice of the material for the damp-proof course. In deep basements, where the subsoil is subjected to occasional flooding, a good site concrete, covered with three layers of asphalte and then a further layer of concrete, will usually be found to be satisfactory in keeping the water out.

The walls are built up to the height of the D.P.C. on the basement floor, and the asphalte is carried over the width of the entire basement wall and over the whole of the surface concrete.

In order to make the walls watertight, it is necessary to cover either the inner, or usually the external, surface of the wall with asphalte, and at the junction of the horizontal D.P.C. an angle fillet is formed to strengthen the coating and prevent any leakage.

In order to do this successfully, a chase must be cut in the wall, or the bottom portion of the wall in the foundations can be made sufficiently wider for the asphalte to make the proper join.

An alternative method is to build the wall in two portions, an inner and an outer wall, and place the vertical asphalte between the two. When the ground level is reached, the vertical D.P.C. is taken over the width of the wall and further extended vertically in the interior of the wall and finally taken out to the face of the wall, completing a tank of the entire walls of the basement. For examples, see Fig. 1.

On sites that are free from water, ordinary D.P.C. slates can be used on the walls, properly bonded and bedded in good cement mortar, and the site concreted with at least 6 in. of concrete composed of clean ballast, sharp sand, and British Portland standard specification cement. This should prevent dampness under fairly normal conditions.

Another method, to waterproof basement walls, is to build an extra outer wall, leaving a small cavity between. This should be ventilated at the top, and weep holes formed on the outer side at the bottom. The top of the cavity can be covered with either a brick on edge or stone coping (see Fig. 2).

Wall Finishings

The tops of external walls are usually terminated with some arrangement that serves as a weathering and an ornamental finish to the walls.

It is usual to bed all such finishings in a good, strong mortar of Portland cement and sand, to assist in preserving the work and prevent dampness from penetrating down into the wall. The most common used is a brick on edge, bedded on two courses of tiles properly bonded and made to oversail both sides of the wall. A similar feature is obtained by substituting an oversailing course of brickwork for the tiles.

On the exposed top portion of the oversailing brick or tile, a cement fillet is formed to act as a watershed, causing rain to drop clear of the face of the wall beneath.

Sheet lead can be used in place of the tiles or oversailing

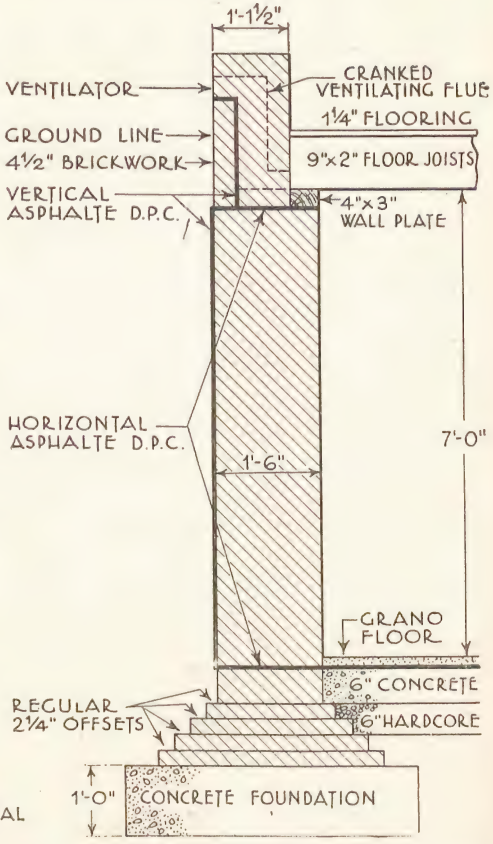


Fig. 1.—SECTION THROUGH BASEMENT WALL, USING ASPHALTE DAMP-PROOF COURSE

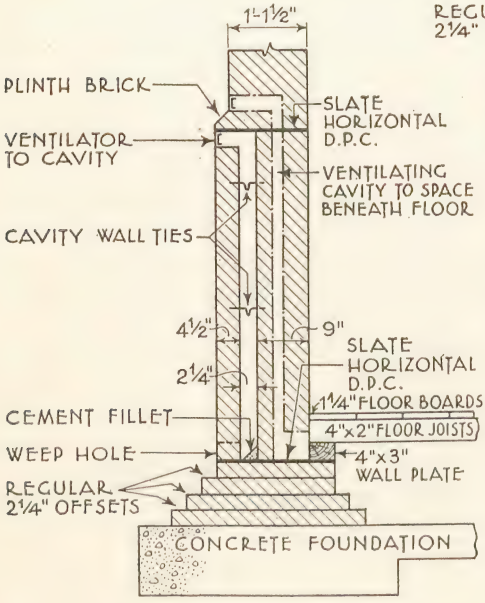


Fig. 2.—SECTION THROUGH BASEMENT WALL, USING DRY DUCT AND SLATE DAMP-PROOF COURSE

brick, and this is projected 1 in. each side of the wall, and bent slightly downwards. Purposely made coping bricks can be procured in a number of shapes and varieties, the most common being the double bull-nosed and the half-round coping bricks.

Stone copings are frequently used. The top is usually weathered to the inside of the building or formed as a saddle-back coping. For example, see Fig. 3.

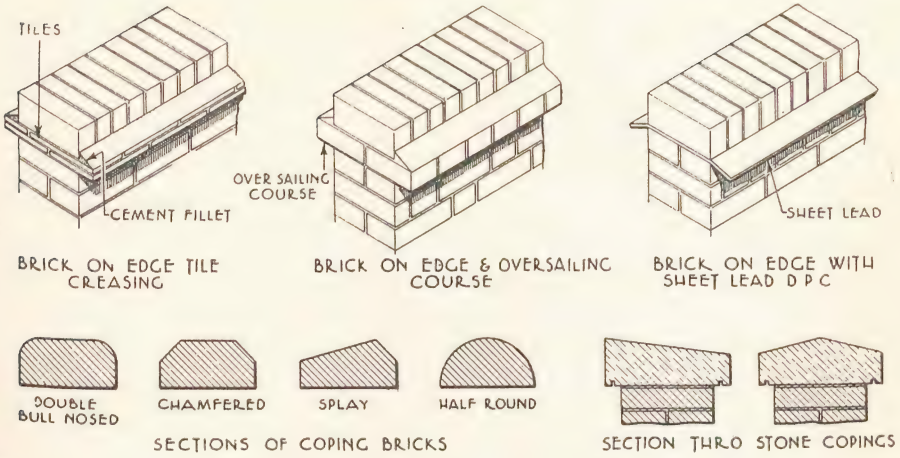


Fig. 3.—Copings and finishings to walls

Plinths and Weathering Bond

Walls of buildings are often made wider beneath the ground-floor window-cill line. This is added to give protection to the actual wall, and also to add to the architectural feature of the building. The finish of the projection or plinth can be effected with purposely made plinth bricks, or by forming a cement fillet weathering on the exposed top portion of the plinth brick.

When setting out the bond for the plinth, the perpends should be arranged so that when the actual or neat wall is reached they are followed up vertically over one another. In order to effect this at the angle, it may be necessary to substitute a three-quarter bat in place of the queen closer (see Fig. 4).

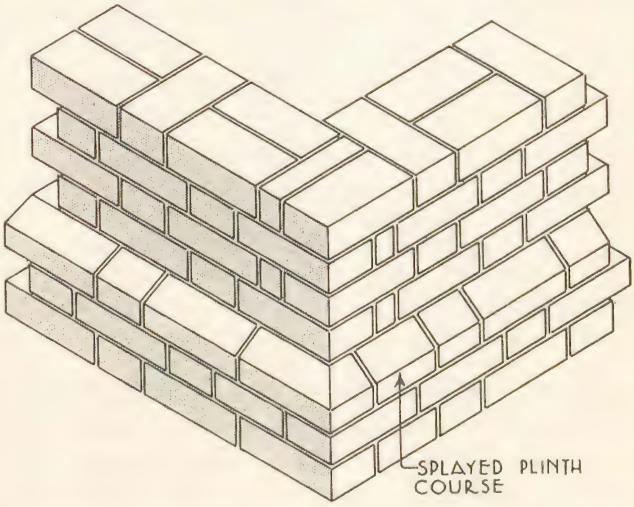


Fig. 4.—Detail of plinth at base of 9-in. wall, built in double Flemish bond

Weathering Bond

Piers acting as buttresses to walls are usually made wider at the base or lower portion, and gradually decreased as the top of the wall is reached.

Fig. 5.—A BRICKWORK ENTRANCE FEATURE

Hartley Brook School: Junior Dept. (*Architect—W. G. Davies, F.R.I.B.A.*)

The finishing of the reduced portion can be effected in several ways.

Plinth Bricks

Purposely made plinth bricks can be used, and at the angles special return or stop-chamfered and mitred bricks are required. An example of this will be seen in Fig. 6, and it must be noted that the bond has had to be re-arranged in the top portion of the pier. This is sometimes necessary, also, in the weathering bond, in order to obtain the correct tie into the adjoining wall. An alternative method of decreasing the width of the pier is to form a *Weathering* or *Water Table*. In Fig. 7 an example of this will be seen. Care should be taken when building to see that the top course in the weathering is level with the horizontal brickwork of the wall. Failure to observe this will create: If kept too low—a very large joint at the top of the sloping or weathered table. If kept too high—the top of the weathering will have to be cut in order to make it level with the horizontal courses in the wall, and this makes it unsightly.

Block Quoins, Indented Courses, and Brick Diapers

The external angles to large buildings are elaborated and made to look bolder by the use of the block quoin. Usually a darker-hued brick is chosen to contrast with the ordinary facings of the building. The blocking courses can be arranged as projections, or be kept flush with the main wall.

The projecting quoin is isolated from the ordinary brickwork at intervals of one or more courses, as required.

The flush, indented quoin is formed by block bonding the specified number of courses into the main wall (see Fig. 8).

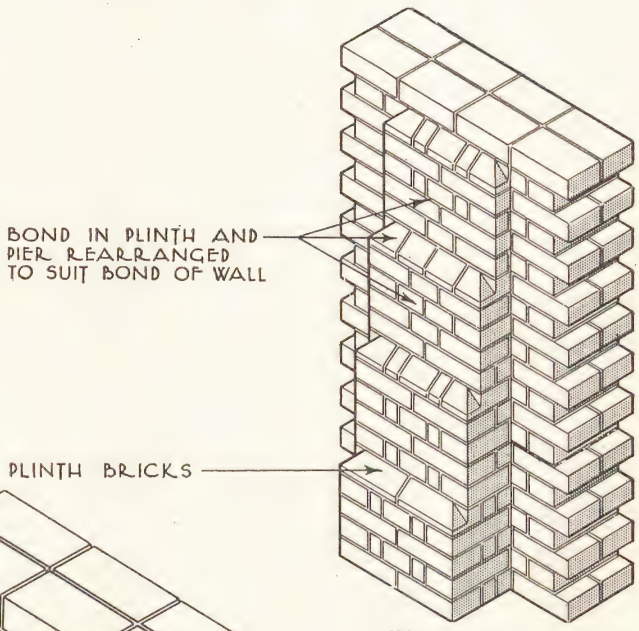


Fig. 6.—DETAIL OF ADJOINING PIER, SHOWING ARRANGEMENT OF PLINTH BRICKS

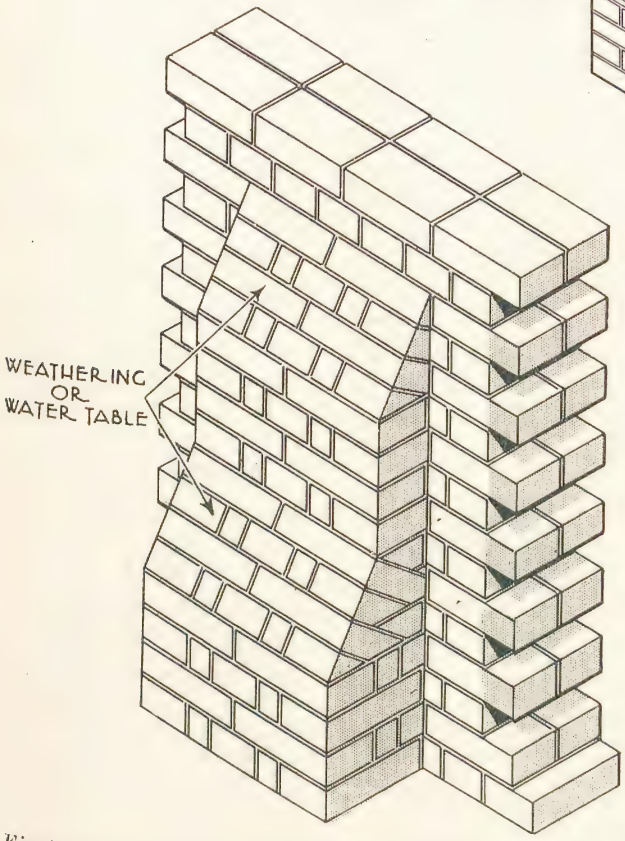


Fig. 7.—DETAIL OF ADJOINING PIER, SHOWING WEATHERING OR WATER TABLE

Indented Courses (see Fig. 10)

Quoins can be formed by recessing at regular intervals a short piece of wall from the external angle one course high. These indents or recesses are sometimes filled with courses of tiles, and the shade from the overhanging course produces an outlining effect.

Frequently the indent is taken across the entire elevation of the building.

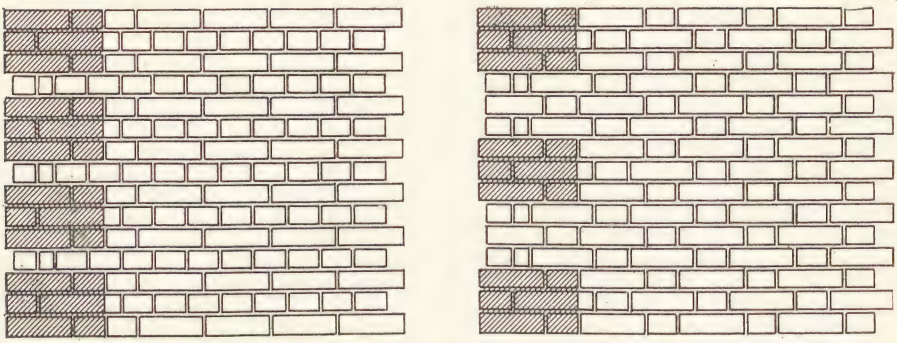


Fig. 8.—DECORATIVE BRICKWORK

Brick Diaper

The plainness of long, blank walls is often relieved by the use of brick diapers. Usually headers, much darker than the colour of the ordinary brickwork, are placed in the wall to form various patterns (see Fig. 9).

Diaper Bond

This arrangement is used for ornamental purposes, and is frequently placed in half-timbered panels, or used as a finish to the top of a parapet wall. For example, see Fig. 11.

Fireplaces, Flues, and Chimney Breast Construction

Flues are necessary to conduct from fires the waste products condensed in smoke, up from the room, through the roof to discharge outside. The foundations for the chimney breast are made the same depth as for the

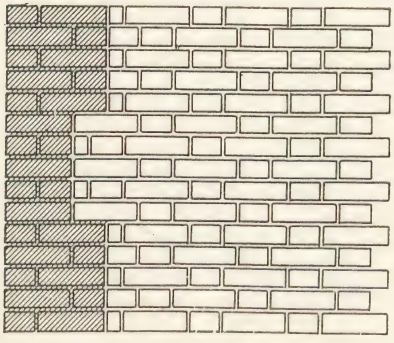


Fig. 8A.—DECORATIVE BRICKWORK

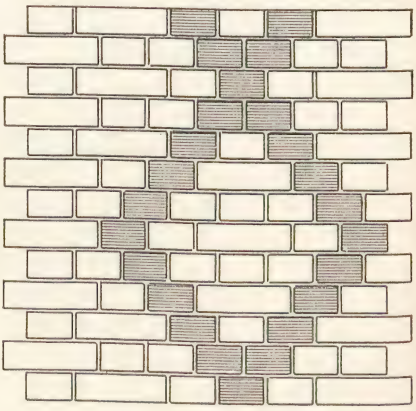


Fig. 9.—BRICK DIAPER

adjoining wall, and for the width of the concrete, the footings and 4-in. or 6-in. spread of concrete must be allowed on all sides of the chimney jambs.

The depth of the chimney breast off the wall is varied according to the type of fireplace or stove to be used. For average use, a recess of 1 ft. 1½ in. deep by 2 ft. 3 in. wide and 2 ft. 6 in. to 3 ft. high can be used. If ranges of the Larbert or Interoven pattern are to be used, then a wider and higher recess will be required.

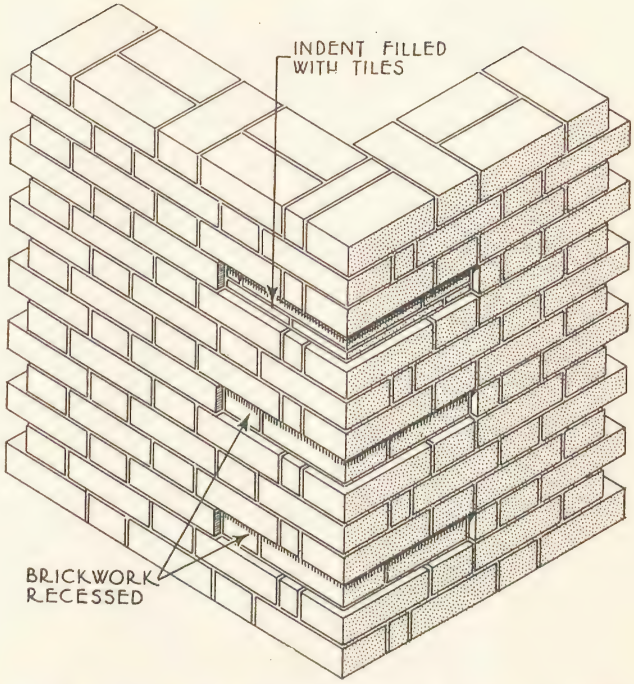


Fig. 10.—Detail of indented quoin in brick and tile

Local by-laws require that every fireplace must have a separate flue, and in most districts the size of the flue for a dwelling-house has to be at least 9 in. by 9 in.

The flues require to be constructed of good, incombustible materials, and for this purpose brickwork and concrete are the most suitable.

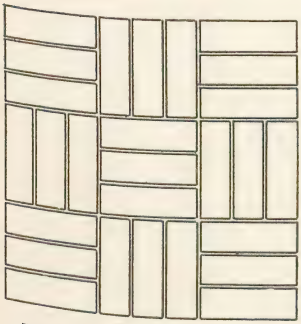


Fig. 11.—Diaper bond

How the Chimney Breast Is Supported

The chimney breast is supported by the chimney jambs forming the fireplace opening beneath. The opening on the external side is covered either with a reinforced-concrete lintel, or a 4½-in.-wide two-ringed rough relieving arch, supported on the under side by a wrought-iron chimney bar, with both ends cut, split, and turned or caulked, which must be built in the wall at least 4½ in. on each side. Internally, the fireplace opening is domed over, commencing at the bed of lintel or springing of the rough relieving

Fig. 12.—FRONT ENTRANCE, YARDLEY CEMETERY CHAPEL, BIRMINGHAM

In Blockley brick—warm orange shade multicolour. (*Architect—James A. Swan, F.R.I.B.A.*)

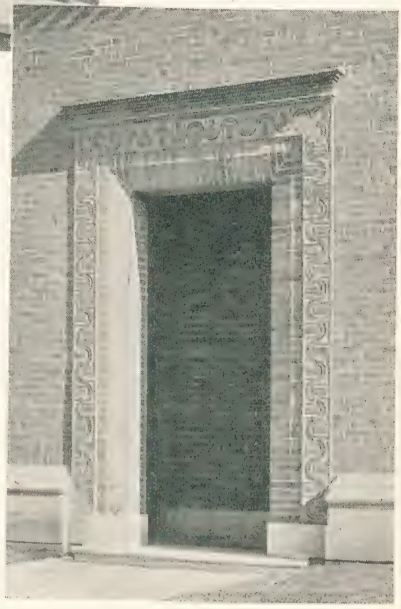
Wall at Back of Fireplace

The wall at the back of the fireplace opening should be at least 9 in. thick, and this must be carried up 12 in. above the bed of the lintel or springing of the arch; in some districts it is necessary to carry up the minimum thickness of the wall for a height of 6 ft. above the opening.

All flues must be "pargeted," or rendered on the inside, as the work proceeds, with lime and sand, arch, until the width of the actual flue is reached in the centre. For example, see Fig. 15.

This operation is termed *gathering over*, and care should be taken to confine this space to the minimum amount, as large, cavernous openings are often responsible for creating down draughts and smoking flues when the fire is first lit.

Fig. 13 (*below*).—ENTRANCE TO THE POST OFFICE, ROYAL HOSPITAL SCHOOL, BUILT FOR THE LORDS COMMISSIONERS OF THE ADMIRALTY. (*Architects—Herbert T. Buckland & William Haywood, FF.R.I.B.A.*)



and if procurable cow dung should be mixed with the mortar.

The external face of the brickwork forming the flues must be pargeted where the flue passes through the floors and in the roof. Flues are usually carried over to one side or the other of the chimney breast, in order that they may form part of the chimney jamb on the floor above, or because it is best to bend the flue in order to hide the light penetrating down from the top (see Fig. 16).

Fig. 14.—BRICKWORK AND ENTRANCE

Lambeth Hospital Nurses' Home. Deputy Medical Superintendent's flat. The tablet shows "The Raising of Jairus's Daughter," by Miss Julian Allan. (*Architect—E. L. Wheeler, F.R.I.B.A.*)

Bends in Flues

Where such bends are necessary, care must be taken not to cramp the width of the flue. At the termination of the bends it is best to have the flues thoroughly cleaned out, and leave a small temporary opening or coring hole, and a board or slate is placed slantwise up the flue, preventing mortar droppings from above falling on the bend and so stopping up the flue. The droppings must be cleaned off the slate or wood every time additional work is added to the chimney breast.

If the flue is taken over into a position very quickly, and the rise is very small, a soot door should be inserted in the flue at the commencement of the rise. The best type has a double-sealing door (see Fig. 17).

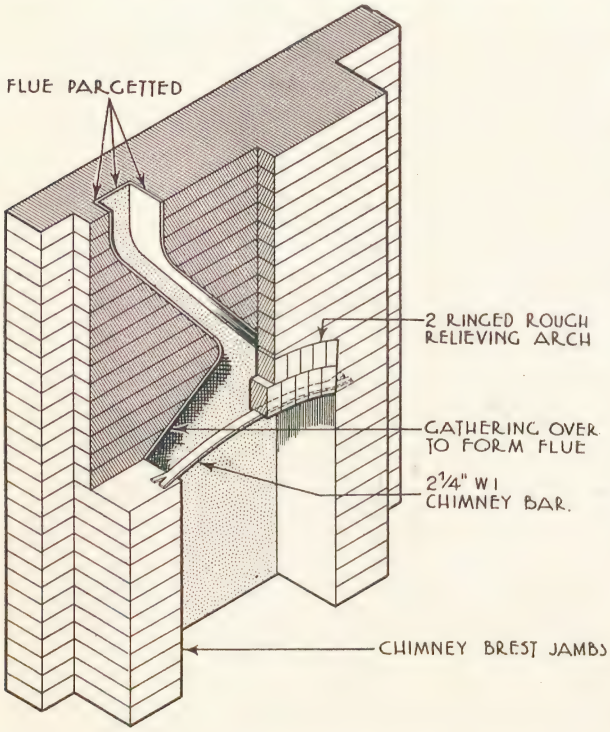


Fig. 15.—DETAIL OF GATHERING OVER FORMED IN A CHIMNEY BREAST

Fender Wall

It is usual on the ground-floor level to build a small wall around the fireplace opening to enclose the hearth; this is called the fender wall. The hearth must be at least 6 in. longer each side of the fireplace opening, and 1 ft. 6 in. wide from the face of the chimney breast. The hearth should be 6 in. deep and formed in concrete (see Fig. 18).

Hearths on Upper Floors

The hearths on upper floors are best constructed of concrete, reinforced with the steel bars passing through the timbers forming the trimmers, and a wood fillet nailed to the inside of the trimmer to further keep the concrete in position.

A small chase in the brick wall enclosing the back hearth can also be left as a bearing for the concrete. The depth of hearth should be at least 6 in.

Trimmer Arch

A trimmer arch is sometimes used, springing from the face of the chimney breast, rising on to the trimmer joists. Centering is built with lagging pieces to support the brick arch, the top of which must be kept down sufficiently to enable the finishing to the hearth to be level with the top of the floor (see Fig. 19).

Grouped Flues

It is usual, when flues are sufficiently near to one another, to join them within the roof of the building and to emerge united in the chimney

stack, each flue being kept in a separate duct, and divided by 4½-in. walls called withes or midfeathers.

To group flues together, an arch is turned from one chimney breast to the other, and the brickwork forming the flues built up on it.

Another method that is largely used is to corbel over each side. The flues follow, due allowance being made not to cripple their width.

While in the course of construction, the corbelling brickwork is temporarily supported by pieces of timber placed slant-wise from breast to breast, and meeting in the centre.

The brickwork to the flues must be properly bonded, and core holes should be left for cleaning purposes. The entire external surfaces of the flues are pargeted within the roof (see Fig. 20).

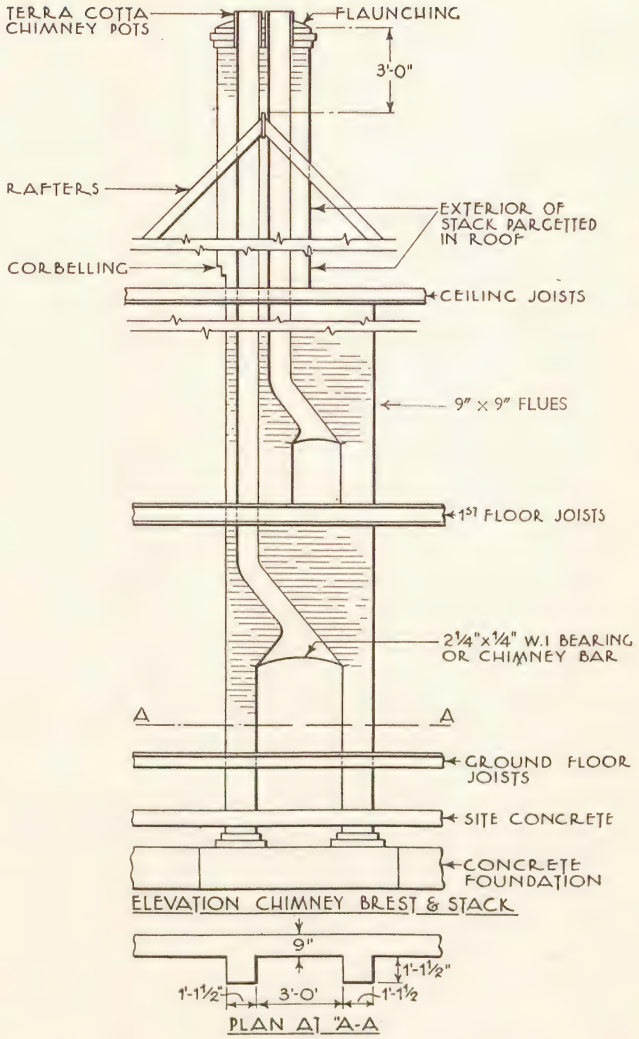


Fig. 16.—Plan and elevation of chimney breast and stack

Chimneys

Chimneys, being exposed to the weather, should be constructed with good, hard bricks, and mortar of Portland cement and sand. A horizontal D.P.C. should be placed about 6 in. above the last point of leaving the roof. This prevents rain that may saturate the brickwork of the

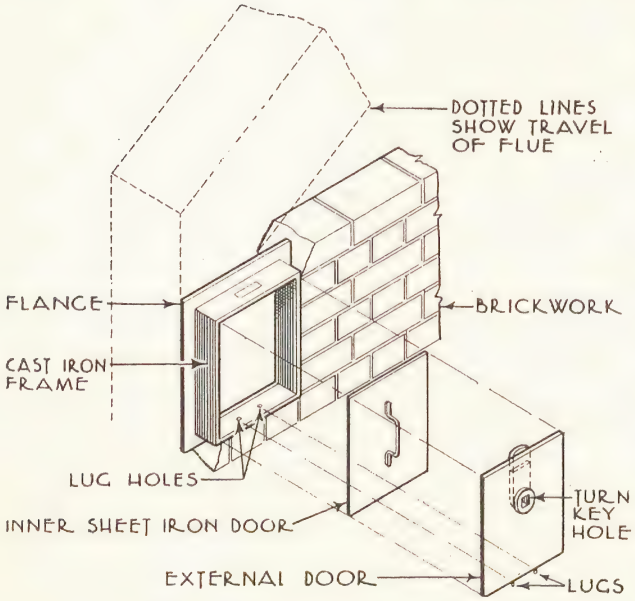


Fig. 17.—DETAIL OF SOOT DOOR

stack from percolating down to the brickwork below. The height of chimney stacks must be at least 3 ft. above the last point of connection with the roof, and if this is below the ridge it is best, in order to prevent down draughts, to carry the stack about 2 ft. above the ridge.

The maximum height of a chimney stack should not be greater than six times its least width, unless given extra support from an adjoining stack or wall. This can be in the form of a stout iron tie-rod, or carried out with a brick arch turned from one stack to the other and finishing with a combined or united chimney head.

The brickwork for chimney stacks must not be less than $4\frac{1}{2}$ in. thick, and care must be taken to keep all of the mortar joints full, and to bond or tie in the courses of the withes or midfeathers alternately into the external walls of the stack. For example see Fig. 21.

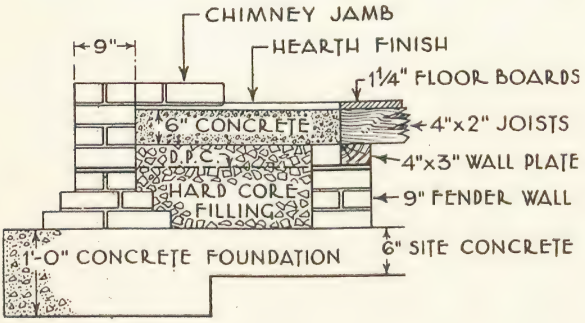
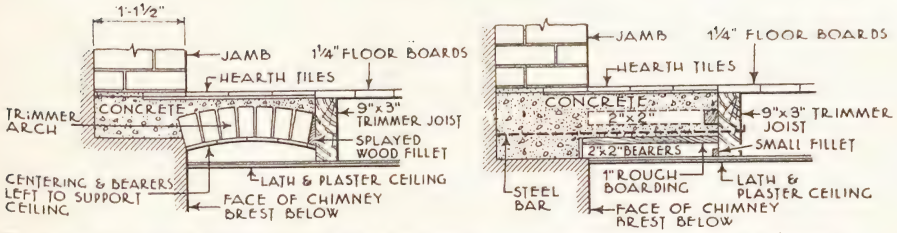


Fig. 18.—SECTION THROUGH HEARTH, GROUND-FLOOR LEVEL

Chimney Heads or Caps

The finial of the chimney stack is usually carried out in some ornamental arrangement. The termination of the flue is also usually lined with a fireclay lining or chimney pot.

To-day, dwarfed chimney pots are very much used, in prefer-



Hearth formed with trimmer arch and concrete. Hearth formed with concrete.

Fig. 19.—ALTERNATIVE ARRANGEMENTS OF HEARTH FOR FIREPLACES ABOVE GROUND-FLOOR LEVEL

ence to those whose projection shows considerably above the finish of the chimney cap.

The following are arrangements for the finishings and decorative features of caps :—

Plain oversailing courses or tiles, and the top course set back to form the weathered top or flaunching.

Oversailing courses combining a dental course. This is an alternate sinking and projection in one course, usually carried out in headers.

Dog's toothing is also used, and the bricks in this course are placed with a triangular corner projecting as an oversailing course.

Purposely made moulded bricks are used, but these do not seem to be much

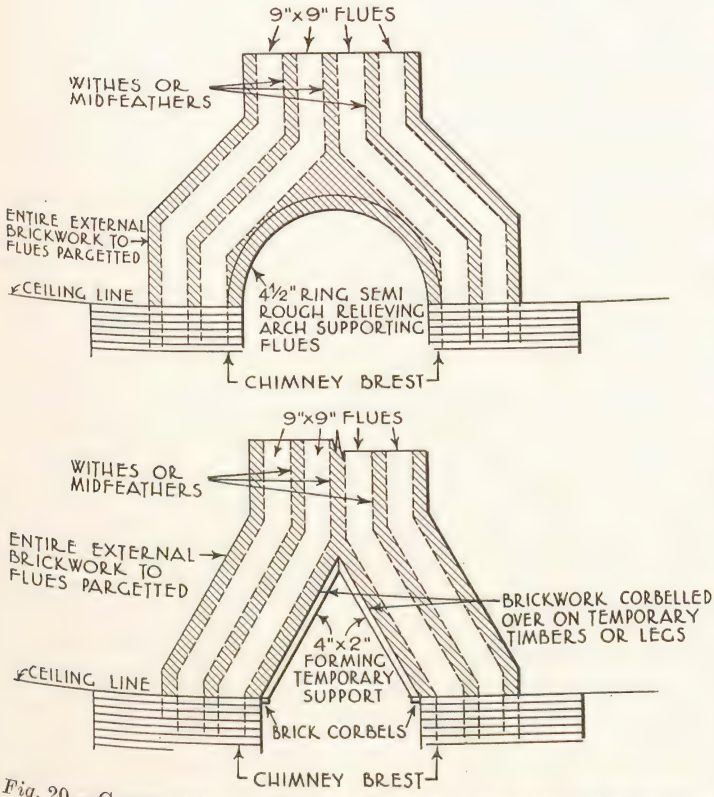


Fig. 20.—GATHERINGS OVER FLUES IN ROOF TO FORM CHIMNEY STACK—ALTERNATIVE METHODS

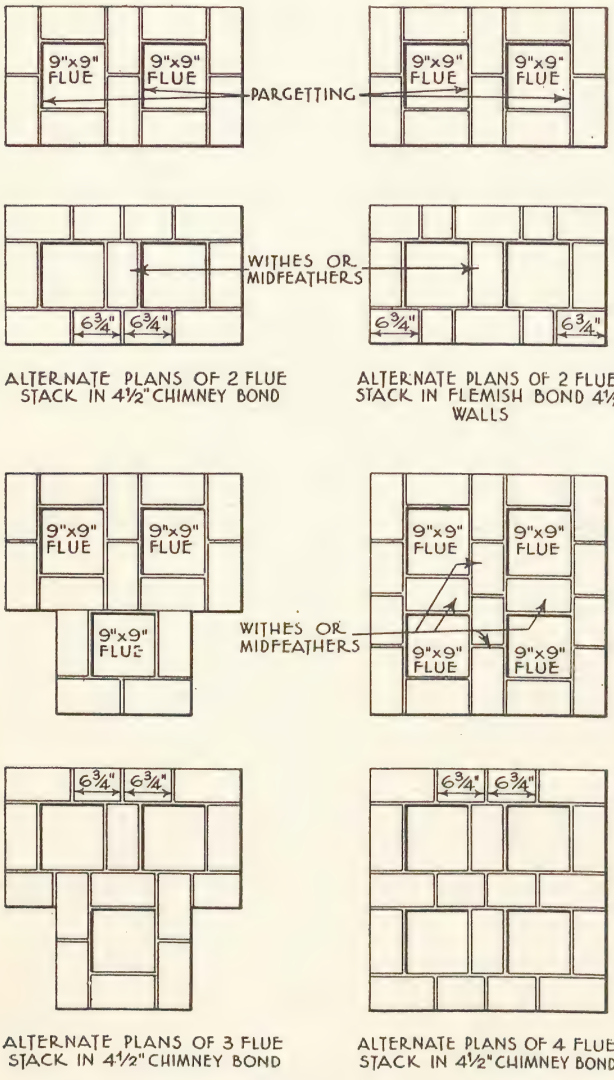


Fig. 21.—ARRANGEMENTS OF 4½-IN. CHIMNEY BOND

in favour to-day.

A popular feature at present is to decrease the stack with small offsets, and in the portion forming the cap the bricks are laid on end.

As it is necessary to make the roof watertight where it abuts the chimney stack, horizontal bed joints should be raked out sufficiently, while the scaffold is in position, to enable the plumber to fix the stepped and apron lead flashings, to minimise the risk of breaking the roofing materials by workmen cutting out the joints after the roofing has been completed. The top of the stack is weathered off in a strong mix of Portland cement and sand, and also the exposed surfaces of any oversailing courses. In order to shape the weathering, a brick core is used and the flaunching completed in the afore-mentioned way. Examples of the arrangements for the finishings and decorative features of chimney heads or caps are illustrated in Fig. 22, on the next page.

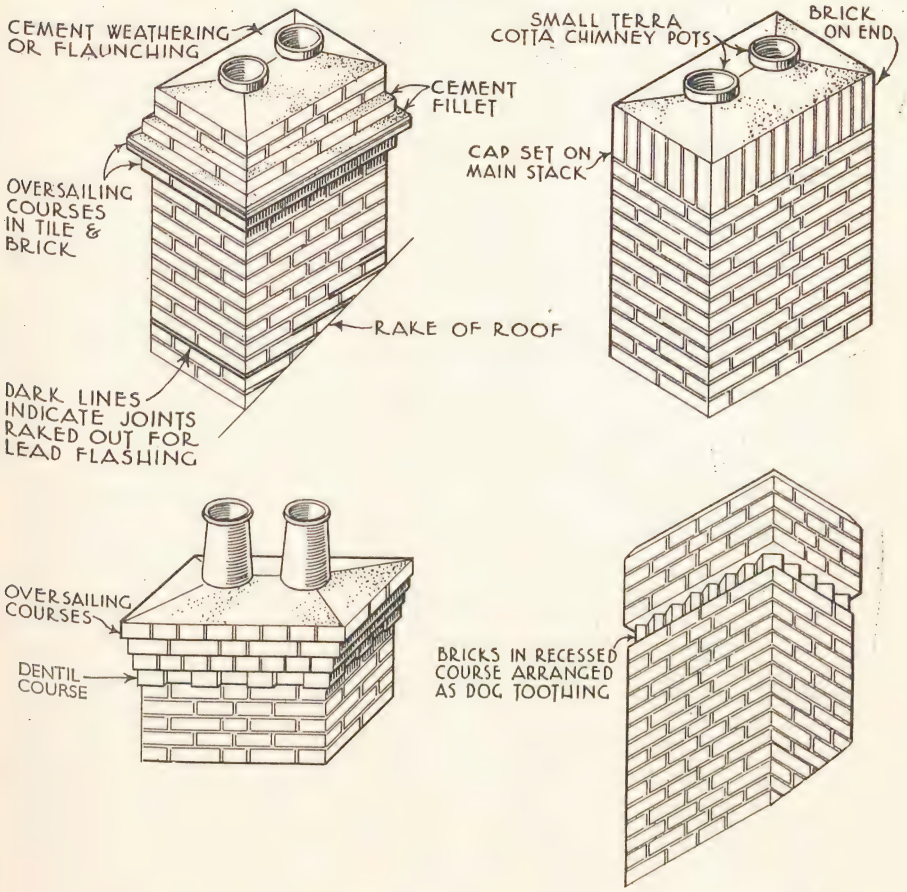


Fig. 22.—CHIMNEY HEADS OR CAPS

QUESTIONS AND ANSWERS

What are the usual methods of terminating the Tops of external Walls to provide a Weathering and an Ornamental Finish?

(1) Brick-on-edge method.
(2) Stone copings.
(3) Coping bricks.

How is the Brick-on-edge Finish applied to Tops of external Walls?

(1) The bricks are bedded on two courses of tiles properly bonded and made to oversail both sides of the wall. On the exposed top portion of the oversailing tile, a cement fillet is formed to act as a watershed.

(2) An oversailing course of brickwork can be used instead of the tiles.

(3) Sheet lead can be used instead of the tiles or oversailing brick. This is projected 1 in. each side of the wall and is bent slightly downwards.

How may the Finish of a Wall Projection or Plinth be effected ?

Either with purposely made plinth bricks, or by forming a cement-fillet weathering on the exposed top portion of the plinth bricks.

What methods are adopted for finishing the reduced portion of Piers acting as Buttresses to Walls ?

(1) Purposely made plinth bricks can be used, in which case special return or stop-chamfered and mitred bricks are required at the angles.

(2) Weathering or water-table method.

What is the purpose of Brick Diapers ?

To relieve the plainness of long, blank walls.

For what purposes is the Diaper Bond used ?

For ornamentation. It is frequently placed in half-timbered panels, or used as a finish to the top of a parapet wall.

How may a Chimney Breast be supported ?

It is supported on each side by a chimney jamb. The opening on the external side is covered by either a reinforced-concrete lintel, or a $4\frac{1}{2}$-in. wide, two-ringed rough relieving arch, supported on the under side by a wrought-iron chimney bar, with each end built into the wall at least $4\frac{1}{2}$ in. on each side. Internally, the fireplace opening is domed over, commencing at the bed of the lintel or springing of the rough relieving arch, until the width of the actual flue is reached in the centre.

What is meant by the Pargeting of Flues ?

This refers to the operation of rendering flues on the inside, as the work of construction proceeds, with lime-and-sand mortar. If procurable, cow dung should be mixed with the mortar. The external face of the brickwork forming the flues must be pargeted where the flue passes through the floors and in the roof.

What is a Fender Wall ?

A small wall usually built on the ground-floor level around the fireplace opening to enclose the hearth.

What are the dimensions required for the Hearth on Ground-floor Level ?

At least 6 in. longer each side of the fireplace opening and 1 ft. 6 in. wide from the face of the chimney breast. The hearth should be 6 in. deep, and be formed in concrete.

THE TIME AND PROGRESS SCHEDULE

By Alfred C. Bossom, M.P., F.R.I.B.A.

THE time and progress schedule is the greatest advance in the way of efficient and economical construction that this century has witnessed. The invention of a Briton, it has suffered the fate of many British inventions—that of being more honoured and practised abroad than in England itself. For the past twenty years at least, it has been recognised in Canada and the United States as a fundamental aid to building, and an immense improvement on the old wasteful and haphazard methods. In Britain a few of the more progressive architects and contractors have adopted it, with excellent results. But it is not yet with us the universal law of building that it might and should be.

Its Origin

Before describing what it is and how it works I must say a word or two as to the circumstances of its origin. The readers of Modern Building Practice, I assume, will know already the rough outline of the history of the skyscraper across the Atlantic, and of the revolution it has wrought in constructional design and technique. It may be doubted whether any other profession or activity has achieved so complete a transformation of methods and materials as the building industry during the past forty years. That transformation has been pre-eminently one of scale. Men were no longer tied down to the old limit of six or seven storeys, which was about as high as the human legs could climb without excessive strain. They could build to the skies. The invention of the lift, the adoption of the steel framework, and the discovery that caissons, hitherto used only as the foundation of bridges, could also be used for land purposes—these, and a vast expansion of electricity as a source of power as well as light, made possible new city building enterprises of a magnitude quite beyond all precedent. That in its turn involved capital in such quantities as had never before been devoted to architecture and building.

Millions were needed and millions were forthcoming. For the first time, the building industry was stimulated by contact with capital and big business—two factors bent on getting their money's worth, knowing the full value of time, and always on the lookout for new, improved, cheaper, and speedier ways of doing things. To reduce building costs, suddenly became an important interest with the huge financial forces that now

went into partnership with the architect and the contractor in a sphere of activity that, being predominately artistic and only secondarily technical and commercial, may not always have been governed by the most businesslike principles.

It was in these circumstances that the time and progress schedule was evolved as a contribution to the problem of how to achieve in buildings the maximum result with the minimum of expenses.

This is a problem which is taken much more seriously in countries like Canada and the United States than it is in Britain. Across the Atlantic the reduction of building costs is recognised as a public question of the first moment. So it is ; it affects all of us.

Who Benefits?

If we were put in the happy and quite attainable position of paying 10 per cent. less on the purchase price of our homes, on our rents, on the costs of our factories, and on the numerous outlays of public moneys involved in slum-clearance schemes and in the prevention of overcrowding, we should realise that this matter of building costs is at once the most national and the most personal and individual of issues in the daily scheme of life.

More than that, architects and builders, and the thirty or more trades that are ancillary to the building industry, all stand to gain if construction is organised, and is known to be organised, on the most efficient and economical lines. As an influence in promoting the public demand for houses, offices, and factories, in steadying employment in the building industry, and in attracting capital to constructional enterprises, there is nothing so potent as a well-grounded confidence that whatever type of edifice is required, it will be erected as cheaply, soundly, and speedily as is humanly possible. To all these ends, the time and progress schedule is the indispensable starting-point. I frankly do not know how any considerable building project can be carried out really well—that is, at the least possible cost and in the shortest possible time—without it.

Preliminaries to Preparing a Schedule

A time and progress schedule is the resultant of an intensive preparatory process that has been going on for months in the form of conferences between the owners, architects, and contractors engaged on a particular building. Long before the work of excavation has begun or a single drill has been put into the ground, all the details of the projected edifice have been hammered out and included in the plans and specifications by the combined teamwork of the designers and directors of the enterprise. It was my experience as the architect of many skyscrapers across the Atlantic that in all these preliminary consultations the utmost freedom and frankness prevailed.

Fig. 1.—THE EMPIRE STATE BUILDING, NEW YORK CITY

This is the tallest structure ever erected by man. It towers nearly a quarter of a mile to the sky, 1,250 ft. high. This beautiful building of eighty-five storeys and 36,000,000 cu. ft. is crowned by a mooring mast for airships.

Architects: Streve, Lamb, and Harmon.

Contractors: Starrett Brothers and Eken.

It was started in November 1929, and was completed in April 1931, less than a year after the first upright piece of steel was set, a striking result of working to schedule. The cost was within a fraction of 75 cents (3*s.*) per cubic foot.

Photograph by Browning, New York City.

Fig. 2.—TOWER OF THE EMPIRE STATE BUILDING, NEW YORK CITY

The architect was placed in full possession of the owner's mind and desires ; he in turn told the owner everything ; experts were continually being called upon for information as to their particular departments—structural engineers, manufacturers and suppliers of materials, specialists in lighting, heating, plumbing, and ventilation work, contractors who knew the market prices and the labour situation, and so on.

From this store of information the architect would complete his drawings and specifications, which, as bills of quantities are not used in Canada and the United States, have to be extraordinarily precise and comprehensive, and finished to the last groove, vent duct, and screw-joint.

It is not until every detail has thus been agreed upon that contractors are invited to tender for the job or the general contract. They then know exactly what they are taking on and so can work out their estimates and pass on to the owner and the architect the full details as to the sub-contractors they have in view. As well as providing the competing general contractors with the full drawings and specifications (with or without a time stipulation attached), the architect also as a rule sends them to the local builders' exchanges so that sub-contractors in the vicinity of the projected building may study them and make their bid.

Contractors send out invitation cards all over the country, probably to eight or ten sub-contractors in each trade ; and from these sub-estimates, checked by the contractor's knowledge and judgment, a total bid is compiled and accompanied by a definite estimate of the time that will be required for each section of the structure. The owner and the architect have thus before them a choice of tenders, from responsible firms, indicating both the cost of the building and the time needed for its construction.

The Contractors' Progress Schedule

Before signing the general contract, it is usual to request the contractors to submit for the owner's and architect's approval a definite progress schedule showing the time when the various sub-contractors must begin their work, when they must finish it, and when the needed materials must be purchased.

How the Schedule Assists Finance

When the general contract is finally allotted and signed, the owner and the architect know what it will cost, who is going to do the work, when it will be begun and when completed, not only as a whole, but in each section. This greatly simplifies the financing of the entire enterprise, and the provision of the sums needed to meet the monthly certificates.

The essential preliminaries to a time and progress schedule will thus be :—

(1) Completely frank discussions between owner and architect, covering all the details of the proposed building ;

(2) Drawings and specifications of the most precise and exhaustive

character, conveying full information to all contractors as to the nature of the job for which they are invited to bid ;

(3) The allotment of contracts and sub-contracts on a strictly competitive basis ; and

(4) The specification in each tender received and accepted of the exact dates on which the sub-contractor is prepared to begin his section of the work and to finish it.

A Bird's-eye View

These preliminaries obviate those disastrously expensive afterthoughts and variations which pile up costs, and make it impossible to prosecute a building enterprise as one continuous activity. They ensure that everything connected with the building shall have been foreseen, debated, agreed upon, and tabulated before any work whatever is started, even on the foundations. They afford the best possible chance that the materials and accessories provided by the sub-contractors shall be the best of their kind, and capable of delivery at the stated time. Finally, they enable the general contractor to form a bird's-eye view of the entire operation in his charge, to map out the sequence of activities, and to arrange well ahead for each component part to take its proper place at the proper date in the process of construction.

Time Required for Excavations

For example, the contractor knows that the work of excavation must be finished by a certain date if the foundations are to be laid by some other fixed date. He therefore takes a number of borings or test holes over the site, and can form from them a workable estimate of how many tons of earth or rock will have to be removed and how long it will take. He is thus in a position to give the undertaking a clean start on schedule time.

Another Example—Stonework

Or take the matter of stonework. After the architect has supplied the contractor with his general drawings, the contractor has to get his shop drawings from the various sub-contractors, and these have to be sent back to the architect for his checking and approval. They then go to the stoneyards, where it is decided that the process of cutting will take, say, ten weeks. The architect and the contractor know, therefore, that if the stonework is to start on a definite date, the finished detail drawings of the architect and the fully checked shop drawings must be in the hands of the masons at least ten weeks beforehand. The same principle applies to every other item in the vast paraphernalia of a large modern edifice.

A Typical Progress Schedule

It thus becomes possible, before any manual or mechanical work has begun on the site, for the architect and contractor to draw up a time

and progress schedule that will deal with every phase, from start to finish, of the projected building. The accompanying reproduction of one of these schedules may be taken as a fair specimen of them all. The first thing that will strike anyone, even a layman, who examines it, is its entire simplicity, a simplicity that has not been reached except as the result of years of experiment and elimination. Such time and progress schedules as I have looked at in England often seem to me to err too much on the side of over-elaboration. Compared with the stark bareness to which the schedule has been reduced in Canada and the United States, I find them rather confusing and difficult to work.

What the Schedule Shows

But nothing can be more straightforward than the chart that is reprinted herewith. Ruled off into four-weekly divisions, it indicates :—

(1) The dates on which the various contracts and sub-contracts were awarded and signed ;

(2) By means of a black bar the date of commencing each section of the work—there are forty-four such sections in the accompanying chart—and the date on which it should be completed ;

(3) By means of a left-to-right-shaded block under the black bar, the actual progress that has been made ;

(4) By means of a right-to-left-shaded block, the dates on which the various materials should be purchased. Some schedules go a useful step further than this, and show the dates on which the architect's completed details should be in the hands of the contractors.

The architect and the general contractor have thus under their eyes a chart that tells them exactly how the work is progressing at any given moment, and for both of them it becomes the supreme and engrossing test of efficiency to see that the schedule is lived up to and that each part of the job is begun and completed on time. This involves keeping a sharp eye on the sub-contractors, and instilling into the operatives an esprit de corps that will give them a personal pride in seeing that they keep pace with the time-table and that, at any rate so far as their own particular section is concerned, the distressing sight of men without material or material without men is not to be seen.

Promoting Teamwork

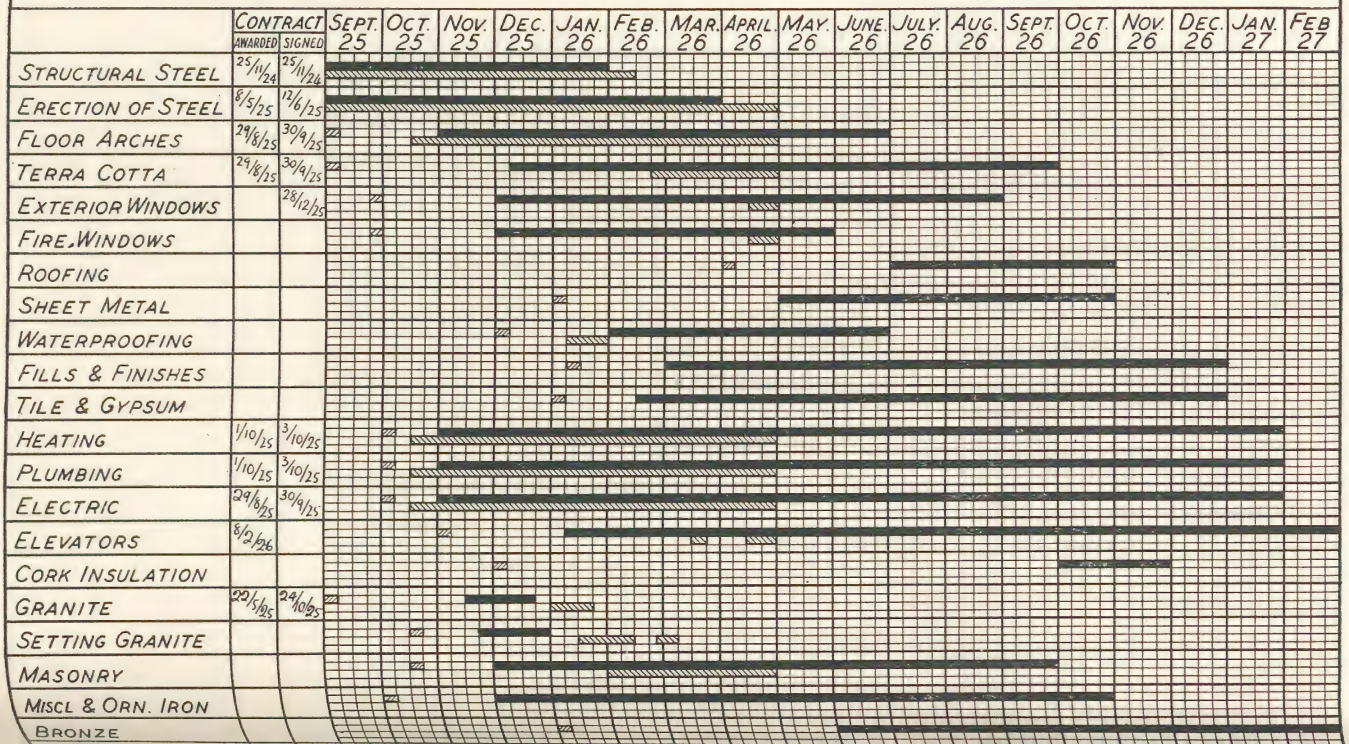
It has been found that one of the best ways of interesting the men in their work is to tell them exactly what they are doing and what is expected of them. The plans of the entire building should be available in the contractor's shanty for anyone to see, and as the work proceeds a duplicate set is posted upon the appropriate floor, so that each operative may know the part he and his section are playing in the general enterprise. If he can read a blue-print, there is nothing to prevent a bricklayer's labourer, once on the job, from learning almost as much about it as the foreman himself.

PROGRESS SCHEDULE

C. HOWARD CRANE, ARCHITECT, DETROIT, MICH.
J. UPTON GRIBBEN, CON. ARCH.

AMERICAN INSURANCE UNION BUILDING, COLUMUS, OHIO.

JOHN GILL & SONS, CONTRACTORS, AGENTS



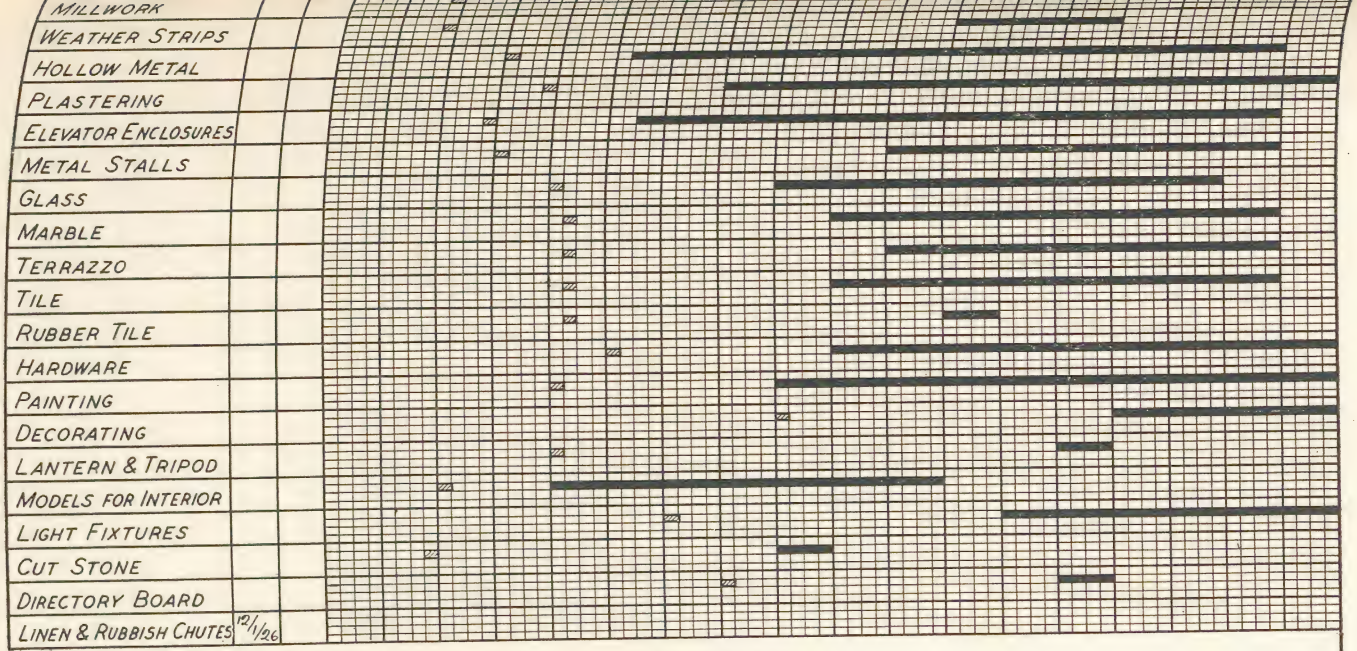


Fig. 3.—A TYPICAL EXAMPLE OF THE PROGRESS SCHEDULES IN ACTUAL USE

Note that the actual progress of the work has been recorded on the chart up to the end of April.

The time and progress schedule which governs the whole undertaking is not a secret locked away in the minds of the architect and general contractor. It is the common property of everybody working on the job.

Each man knows when the work of his section has to be finished, and it becomes a point of honour with him, or at least a matter of keen competitive rivalry, to see that it is finished on or before the appointed date, and that no other sections are kept waiting through his slackness or inefficiency; and there is often thus generated among the hundreds of operatives who may be employed on a large building, a zeal and good fellowship and a feeling of adventurous enthusiasm such as one more often encounters on a battleship than in civil life. The lack of secrecy that surrounds the building operations under these conditions across the Atlantic, and the habit of letting the men know just what the time and progress schedule expects of them, are most potent factors in promoting keenness and teamwork.

Architects and contractors, men able to inspire respect and confidence, and with the gift of leadership, do not find that the operatives working under them are their chief worry. Their chief worry is the sub-contractors, who may be scattered all over the country, and the problem of seeing that they deliver their goods on time, in accordance with the schedule.

Progress Reports

The general contractor in charge of the whole job expects and receives from the sub-contractors every week or every fortnight full reports as to the progress they are making with their orders. If it is apparent that one of the sub-contractors is falling behind the schedule, he is urged by headquarters to put more men on the job and to speed up. If this proves ineffective, an inspector is sent down to discover the root of the trouble and to remove it. When the news comes that the sub-contractor has completed his job in his shop, or at his yard or quarry, and is ready to ship the finished product, "expeditors," as they are called, are frequently dispatched to the spot to superintend the loading of the material and to travel with it on the train, to see that it is not stalled at some junction but will arrive "according to plan." Nothing whatever is allowed to stand in the way of the time and progress schedule functioning with regularity, and to the prescribed dates. Everything depends on that.

Meetings on Site

With this object always in view, weekly or fortnightly meetings are held on the site itself between senior representatives from the architect, the builder, and each sub-contractor. At these meetings each man, in front of all the others, is requested to state definitely the condition of his work in the light of the schedule and, if it is behindhand, to give the reason and to inform the meeting what remedy he proposes. Minutes are

kept, so that it is possible to see later on whether the various suggestions put forward have been carried out and have borne fruit. The information thus gathered together is embodied at least once a month in a report that is sent in triplicate to the architect, the general contractor, and the owner. The weak spots in the organisation are thus made clear while there is still time to deal with them. Trouble is forestalled before it comes to a head, and unforeseen difficulties are taken in hand the moment they appear. Moreover, a closeness of co-operation is formed among the firms and interests engaged on the job that makes it easy and natural for them to stand by one another, and to extend practical help whenever it is needed.

The Weather Question

There are of course some things—a strike, for instance, in the steel industry or among the granite quarries—that leave the contractor and his sub-contractors helpless, and that are bound, when they occur, to disarrange the time and progress schedule. But there is one form of interruption to which great deference is paid in England, but of which little or no notice is taken in America—I mean the weather. If it rains or snows or freezes in England, the policeman and the postman call in the aid of mackintosh and overcoat, and carry on. But the building operative as a rule goes home. In America, the necessity of observing the time and progress schedule, and the stimulus to inventiveness imparted by that necessity, have resulted in building becoming an all-the-year-round activity, with no expense for insurance policies against the weather, and no acrimonious quarrels over the question of " bad-weather " pay.

A Case in Point

A dozen years ago I had in hand a large bank building in Buffalo, N.Y., which has approximately the same rainfall as England, but greater dampness, a much lower temperature, and a far heavier snowfall. The building was 260 ft. long and 23 storeys high. We built every single working day throughout the year, sometimes with the thermometer below zero. When it rained or snowed or froze we ran tarpaulins round the steel frame of whatever storey we were working on, and lit coke braziers. By handing out mackintoshes, rubber boots, and sou'-westers to the men, we kept them warm, and by putting anti-freezing mixture into the mortar we enabled them to go on with their work. The whole of the building, which cost £1,000,000, was finished in the scheduled time of less than fifteen months, fully three months of which were occupied in setting the caisson foundations ; and not a man groused or was the worse in health for an experience that filled his pay envelope. Working to a schedule brings with it a fertility in devising the ways and means of overcoming obstacles that otherwise might be accepted as insuperable.

The great virtue of the time and progress schedule is that, by squeezing out waste time, and by organising a building operation as a concerted piece of teamwork so that it proceeds step by step instead of spasm by spasm, it has reduced building costs, while adding to the speed of construction, to the wages of the operatives, and to the returns reaped by the architect, contractor, and owner alike.

A Striking Result of Working to Schedule

Thanks to the time and progress schedule, the highest building in the world, the Empire State Building, 1,250 ft. high, a monster of eighty-five storeys and 36,000,000 cu. ft., was completed in less than a year after the first upright piece of steel was set.

Collaboration Pays

I need not recapitulate records of speedy and scientific construction that will probably be familiar to all my readers. So long as they bear in mind that these records would not have been made without months of planning ahead and the fullest and frankest consultations between owner, architect, and contractor and the heads of the building operatives' organisations, my purpose is satisfied, and the time and progress schedule is then seen in its true light as both the instrument and the product of a long, intimate, and in my opinion wholly beneficent process of collaboration. Am I wrong in thinking that there is too little of this collaboration in England ?

The greatly quickened pace of building which results from the time and progress schedule performs a double financial service. In the first place it reduces the time during which money has to be paid out, and in the second place it hastens the time when a return will be received from the finished and occupied building. This in its turn encourages capital to enter upon building enterprises, helps to create a demand for more buildings, and so goes a long way towards ensuring a continuity of employment in the building industry, and towards taking it out of the category of seasonal trades. I have spoken already of the far-reaching social and private benefits conferred by anything that effects an all-round reduction of building costs. To this end there is no agency within my knowledge that even begins to compare with the time and progress schedule.

Some Interesting Comparisons

Some curious and significant facts emerge when one starts an inquiry into the comparative costs and the rates of wages on a big building in America and in England. Take, for instance, the Empire State Building in New York and the I.C.I. Building in London. Both were erected by

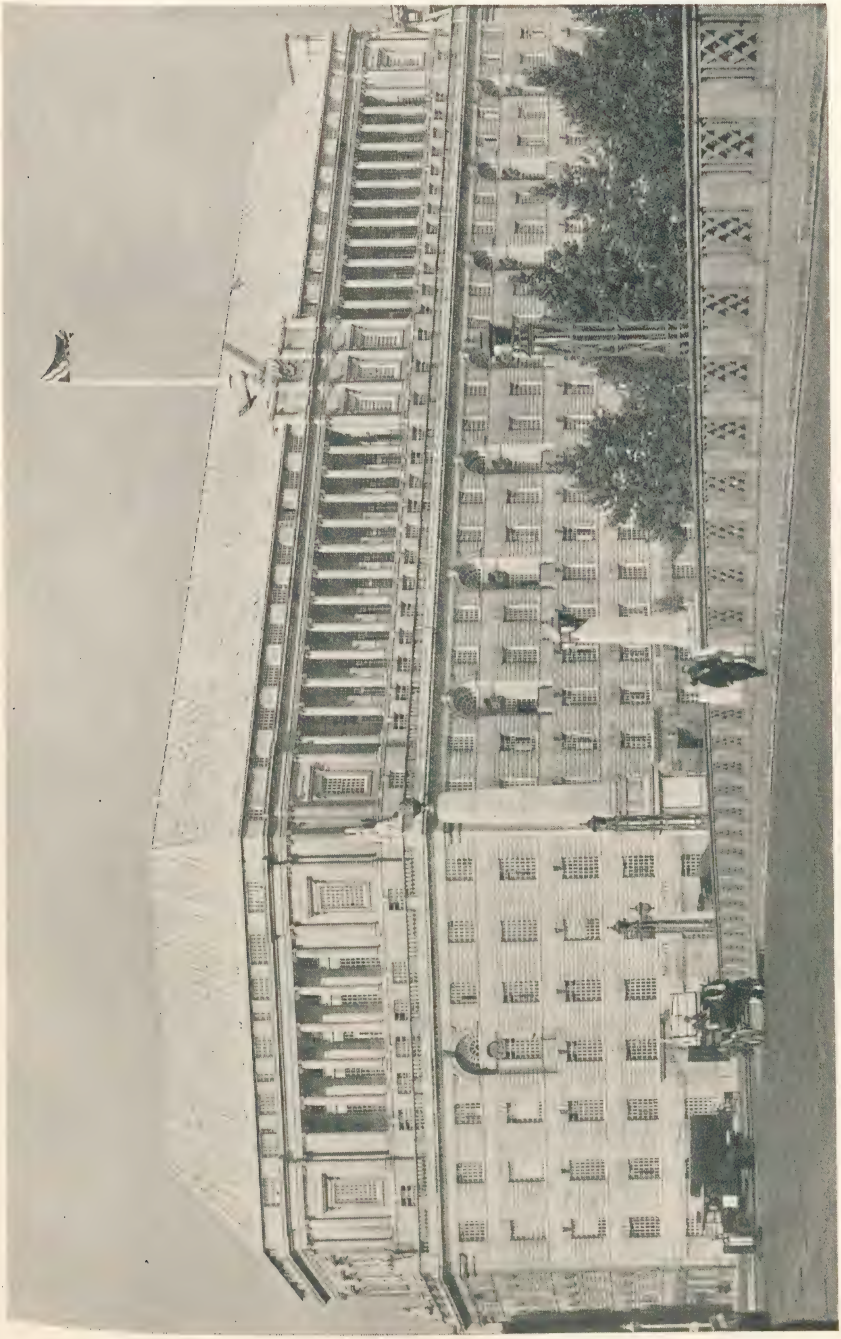


Fig. 4.—IMPERIAL CHEMICAL HOUSE
The time and progress schedule was used throughout during construction.

Fig. 5.—THE PRE-VIEW

Just as the architect has models to give in advance a bird's-eye view of the completed structure, showing how the various masses unite without interference, so the time and progress schedule may be used to provide in advance a bird's-eye view of the work of construction, showing how the activities of the men engaged on the work dovetail into each other, thus avoiding unnecessary delays and overlapping.

firms of the highest standing in their respective countries, and by the aid of the time and progress schedule. Each cost within a fraction of 3*s.* per cubic foot, and I think it may be accepted as a fact that this close approximation was no accident, and that the unit cost of erecting comparable buildings in Britain and America is virtually the same. But there is a very different tale to tell when we examine the wage sheets.

Labour Costs in Britain and America

A year or two ago, brickwork, for example, cost over twice as much across the Atlantic as in England, but the men who handled it in Canada and the United States got paid 5*s.* 10*d.* per hour as against our 1*s.* 8*d.* Structural steel cost 350*s.* per ton in America and 370*s.* in Britain. But the American steel worker got 4*s.* 2*d.* per hour, and his opposite number in England 1*s.* 5*d.* Carpenters, plumbers, and bricklayers were receiving in wages about 12*s.* 8*d.* in Britain. In Canada and the United States their respective wages were 55*s.*, 55*s.*, and 64*s.* per day, and for no harder work and assuredly for no better craftsmanship. The same or similar disparities run all through the various sections of the building industries on the two sides of the Atlantic. This is to say, the Americans pay the building operatives from three to five times the wages they receive in England, and yet their completed buildings cost no more, are finished more quickly, and bring in an earlier and larger return.

Efficiency at the Top Means Higher Wages for the Men Down Below

How is that anomaly to be explained ? The explanation lies almost on the surface of what I have written in describing the time and progress schedule. It is because the Canadians and Americans have applied forethought and system to the problems of building that they can afford to pay and are glad to pay high wages. It is because our practices in England are by comparison faulty and antiquated, and our technique imperfect, and our teamwork and the habit of co-operation but feebly developed among us, that wages throughout the British building industry stand at their present deplorably low level. By perfecting their methods and warring ceaselessly on waste, by planning, organising, and working together, they can cheerfully see 60 per cent. of the cost of transatlantic building go in wages, and 40 per cent. in materials. The corresponding figures for England are precisely the reverse—60 per cent. of the cost of a British building goes in materials and only 40 per cent. in wages. Can it be doubted for a moment which is the healthier dispensation ? Are not these figures a confirmation of the truism that, given efficiency at the top, labour costs, however high, are unimportant, and that without that efficiency wages are bound to rule low ?

For Your Consideration

It will be seen, therefore, that the time and progress schedule and its implications are matters of great moment because they contain the secret of all economical and efficient building. It has been reckoned that because its adoption in England is the exception and not the rule, and because we thereby lose the advantages of the higher technique and organisation that go with it, our national building bill, which amounts to some £300,000,000 a year, is 10 per cent. higher than it need be. Happily, however, the success of the few British firms of architects and contractors which have experimented with the time and progress schedule has been so outstanding that I am hopeful their example may percolate through the rank and file of the industry, and may even reach the Government and the local authorities, who are responsible for about half the building that is done in Britain. More perhaps than any other country Britain needs to be rebuilt, and it will be of the utmost consequence to us as a nation and as individuals whether she is rebuilt on the old often-casual, rule-of-thumb, and wasteful lines, or whether full advantage is taken of the revolution in building methods that is symbolised by, but by no means confined to, the time and progress schedule.

QUESTIONS AND ANSWERS

What are the essential preliminaries to the drawing up of a Time and Progress Schedule ?

(1) Discussions between owner and architect covering all details of the proposed building.

(2) Drawings and specifications of precise and exhaustive character conveying full information to all contractors as to the nature of the job for which they are invited to bid.

(3) Allotment of contracts and sub-contracts on a competitive basis.

(4) The specification in each tender received and accepted of the exact dates on which the sub-contractor is prepared to begin his section of the work and to finish it.

How can a contractor form a workable Estimate of the Date on which the Work of Excavation will be Finished ?

By taking a number of borings or test holes over the site, he can form from them a workable estimate of how many tons of earth or rock will have to be removed, and how long it will take to excavate.

MODERN TILING PRACTICE

PLAIN TILING

ONE striking difference between old and new methods should be noted at the outset. Until recent years it was the custom to try to prevent the penetration of water by the lavish use of mortar in the form of torching and bedding. In modern practice the use of mortar is deprecated. We ventilate, rather than seal, our roofs, and there can be no doubt that it is the better practice. The life of the tiles and battens is prolonged, and the drying out of wet tiles is accelerated, by a current of air passing between them.

Roof Pitches

The question of rafter pitch for plain tiling must always be considered in conjunction with the other factors involved : permissible cost, position and exposure of building, and kind of tile.

The cost of all items increases as the pitch is raised, and this is a factor to which architects have to give consideration. A sheltered roof can safely have a slower pitch than could be used for one in a very exposed position. In general, plain tiling demands a steeper pitch than does any form of single-lap tiling, but that is not to say that the appearance of a house with a single-lap tiled roof will not be improved by having a roof of fairly steep pitch rather than one of 30°.

Experience has shown that in England a pitch of 45°, there or thereabouts, is satisfactory for a plain-tiled roof under ordinary conditions of exposure. Greater security can be obtained in exposed positions by (*a*) increasing the lap or (*b*) raising the pitch.

A point to be noted is that in plain tiling the effective pitch (Fig. 1) is several degrees less than the pitch of the rafters, particularly when, as in the illustration, a well-cambered tile is used. It is of the greatest importance that this difference should be remembered in connection with valleys. If the pitch of a common rafter is 40°, the pitch of the valley rafter is 31°, and a well-cambered valley tile used on such a roof may have an effective pitch of as little as 20°. With a swept or laced valley the risk of penetration is even greater than with a valley tile, and a generous width of felt is advisable with swept or laced valleys if the common rafter has a pitch less than 45°, particularly if the tile is a relatively porous, hand-made one.

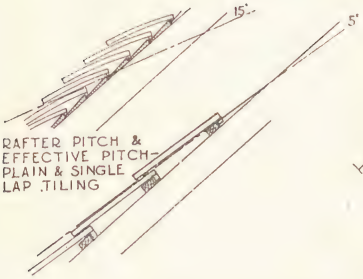


Fig. 1.—RAFTER PITCH AND EFFECTIVE PITCH

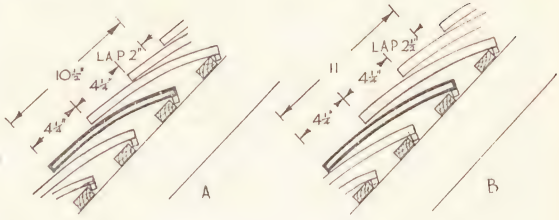


Fig. 2.—GAUGE AND LAP—11-IN. AND 10½-IN. PLAIN TILES

Gauge and Lap

The lap should always be mentioned in any specification, since tiles vary in length, and to specify only the gauge is to run the risk of getting insufficient lap. Two and a half inches is the minimum lap for plain tiling, and, as Fig. 2 shows, while this lap is obtained with a $4\frac{1}{4}$-in. gauge where a tile 11 in. long is used, a $10\frac{1}{2}$-in. tile would give only a 2-in. lap.

Roof Preparation

The following are the alternative forms of roof preparation adopted in modern practice :—

(*a*) Open battens : ideal from the point of view of roof ventilation, but obviously unsuitable where use is to be made of the roof space.

(*b*) Feather-edged boards : less ventilation and less dust and soot in the roof space than with (*a*), and rather better " tying-in " value ; should never be used with a relatively porous, hand-made plain tile.

(*c*) Plain boards and battens : better than either (*a*) or (*b*), and giving, with good boarding, a practically dustproof roof space. The addition of counter-battens is well worth the small extra cost.

(*d*) Untearable felt and battens : comparable in value with (*c*), but the felt must be untearable (that is, a bituminous felt with a strong canvas or other base), or the tilers will put their feet through it.

(*e*) Plain boards, felt, counter-battens, and battens : the ideal roof preparation from all points of view, but the most costly.

Sizes of Battens

For plain tiling, battens may be of any scantling from 1 in. by $\frac{3}{4}$ in. up to 2 in. by 1 in. A good ordinary size is $1\frac{1}{4}$ in. or $1\frac{1}{2}$ in. by 1 in. In plain tiling, the gauge should be taken from top to top of battens, not from centre to centre.

Eaves

A section through the eaves in a plain-tiled roof is shown in Fig. 3A. This also illustrates a normal method of closing the soffit of overhanging

rafters. Fig. 3B shows how an open soffit should be formed. Note the use of feather-edged boarding in place of battening from eave to wall-line. Eaves are occasionally specified as "to be bedded," but this is unnecessary and detrimental. In Fig. 4 the construction at eaves is clearly shown, the batten for the eave tile being the first above the fascia. The tiler's method of loading the roof is also seen: a tiler's mate will carry up a ladder as many as forty to forty-five plain tiles on his head, a weight of perhaps 100 lb. or more.

Sprocketed eaves improve the appearance of a roof, but care should be taken that the sprocketed part is not of too slow a pitch. No part of a plain-tiled roof, excepting, of course, hips and valleys, should be of less than 40° pitch.

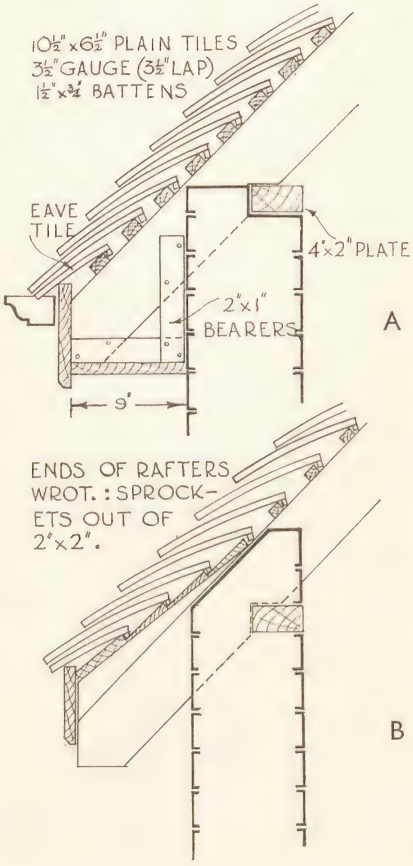


Fig. 3.—SECTIONS THROUGH EAVES IN PLAIN TILING

Nails and Nailing

Nails for tiling and slating may be conveniently considered under one heading.

The kinds ordinarily in use are of galvanised iron or steel, zinc, yellow cast composition, and copper.

Galvanised nails are used for ordinary tiling work, where the weight of the unit is largely taken by the nibs. For slating or nibless tiling, where the nail takes the whole weight, galvanised nails are considered to be unsuitable. Although gauges as fine as 12 and 13 are frequently used, a minimum of 11 gauge is recommended. The length should be at least 1½ in. for tiling: a nail 1¼ in. long, if used with a thick tile, will not give sufficient fixing into the battens.

Zinc nails are cut, not cast, and are satisfactory on all jobs excepting those where the nails may be exposed to fumes that are injurious to zinc. A minimum length of 1¼ in. for small slates, and 1½ in. or 2 in. for large slates, is recommended. Average weights of zinc nails are :—

1½ in. . .	4½–5 lb. per 1,000
1¾ in. . .	6½–7 lb. ,, ,,
2 in. . .	10–11 lb. ,, ,,

Fig. 4.—CONSTRUCTION AT EAVES IN PLAIN TILING

Yellow cast-composition nails are made of an alloy of copper, zinc, and tin. They are practically indestructible under all conditions, and have the advantage over copper that they are harder and more readily driven. Composition nails are used for all kinds of slating and tiling, but are costly: about 2*d.* per pound more than copper nails, and about four times as much as galvanised. Composition nails are about 10 per cent. heavier than copper.

Copper nails are generally used for slating, and for this purpose are unequalled. Of the many slated roofs that have to be stripped and re-slated, in probably 95 per cent. of the cases the trouble is due to defective nails rather than to any defect in the slates themselves. Galvanised nails should never be used in slating: copper, zinc, or composition are safer. Average weights of cut copper nails are :—

1½ in. .	. 4½ lb. per 1,000
2 in. .	. 10 lb. ,, ,,

Cast copper nails are lighter than the cut variety.

Cost of Nailing

It is not possible to give costs per square for nailing: each class of work requires a different number of nails per square. Plain tiling is ordinarily nailed at every fourth or fifth course, with two nails to each tile. Fifth-course nailing laid to a 4-in. gauge thus requires $554 \times 2 \div 5$,

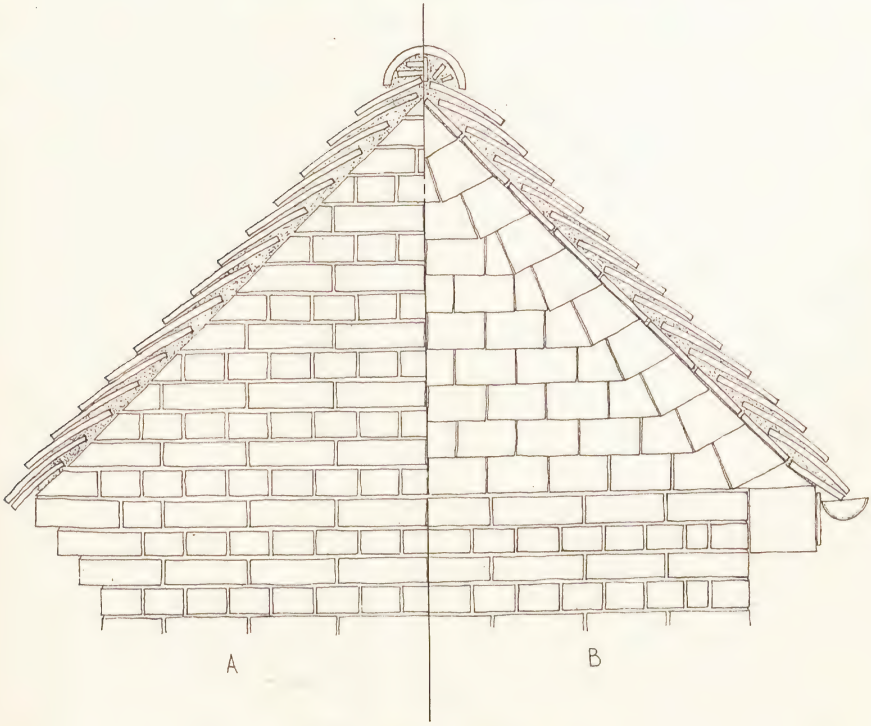


Fig. 5.—VERGES IN PLAIN TILING

A. Verge bedded and pointed. B. Bedded and pointed, with course of plain tiles as undercloak. Note Winchester cut of vertical tiling against undercloak.

or 222 nails per square net, and if the nail used is a copper nail 1½ in. long, weighing 4½ lb. per thousand, and costing 10*d.* per pound, the cost per square for nails would only be about 11*d.* This would allow a reasonable percentage for waste. The 554 in the above calculation is the number of tiles per square. Other examples are worked out by the same method.

Verges

Verges ordinarily project 2 in. over a brick wall or barge board, but on high buildings this should be increased. Verges may be bedded and pointed only (Fig. 5A), or bedded and pointed with the addition of one or more courses of plain tiles laid flat as undercloak (Fig. 5B). The latter method is preferable for two reasons : the appearance is improved, and the verge is given a slight tilt, which helps to prevent water from dripping over the edge of the verge.

Where vertical tiling occurs under a verge, as in Fig. 5B, the undercloak is essential if a neat finish is to be made between the vertical tiling and

undercloak. This illustration also shows the method of splay-cutting known as Winchester cut, a finish that is becoming increasingly popular. It is, of course, more expensive than the continuation of the courses of vertical tiling in a straight line until they meet the under side of the verge.

Figs. 6 & 7.—HIP COVERED WITH HALF-ROUND RIDGE

Note use of lead where hip passes near chimney stack.

Ridges

Ornamental ridges are now rarely used in tiling: nor, for that matter, in slating either. Most architects favour, for tiling, the half-round ridge, bedded and pointed in cement mortar. The

practice of bedding ridges, hips, etc., in lime and hair mortar, and pointing in cement mortar, is also dying out. It had no practical advantage, and was rarely carried out to specification.

Fig. 8.—BONNET HIP TILING

Hips

Hips may be :—

(*a*) Covered with half-round or other ridge tiles (Figs. 6 and 7).

(*b*) Of bonnet hips (Fig. 8).

(*c*) Of hip tiles (Fig. 9).

(*d*) Mitred (Fig. 10).

Half-round ridge may be used with either hand-made or machine-made tiles. Bonnet hips are usual in good-class hand-made tile work, and hip tiles are associated with machine-made tiles. Mitred hips are commoner in slating than in tiling.

Here are a few points to be noted :—

(1) Hip irons are needed with a ridge on the hip. Their function is to prevent the whole length of hip ridge from slipping.

Fig. 9.—HIP TILING WITH CLOSE-FITTING HIP TILES

(2) Every bonnet hip or hip tile has to be nailed, and there is thus no necessity for hip irons.

(3) There is one bonnet hip or hip tile to each course of tiles on either side of the hip. If the two pitches coming into a hip are different, the longest common rafter on the steeper pitch will be shorter than that on the slower pitch, but the number of

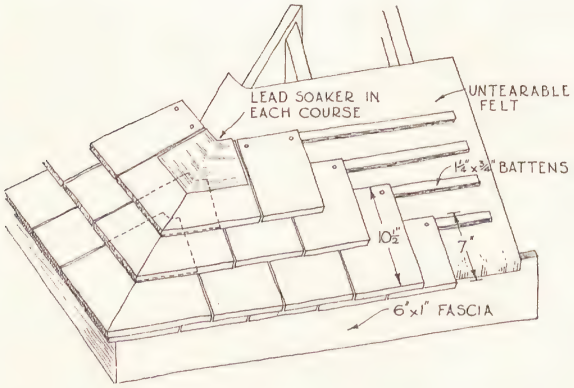


Fig. 10.—MITRED HIP IN PLAIN TILING

courses of tiling remains the same. Therefore, on the steeper pitch the gauge is shorter, and provision must be made for this when battening. The rule is: where bonnet hips or hip tiles are used, the battens must intersect at the hip.

These remarks apply also to valley tiling and mitred valleys and hips. Where ridge tiles are used on a hip, or valleys are of metal, the courses need not "follow round."

Valleys

The valley is the most vulnerable part of a roof, and needs extra care on the part of the tiler. The usual forms of valley are (*a*) valley tile, (*b*) mitred valley, (*c*) laced valley, (*d*) circle or swept valley, and (*e*) metal valley.

The valley tile (Fig. 12) is the commonest and most serviceable form for use with plain tiling. Valley tiles are not nailed, as the tiles on either side keep the valley tile in place.

The mitred valley is not much used in modern practice, and the open valley only in cheap work. Both involve the co-operation of another trade, and both are less satisfactory than the tiled valley.

Laced and swept valleys are pleasing in appearance, but expensive in both labour and material, as so many tiles have to be cut. A laced valley is shown in Fig. 13. Note the characteristic upward sweep of the courses as they approach the valley, and compare with the tiled valley of Fig. 12.

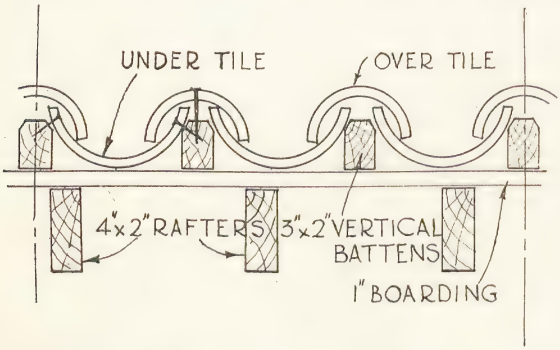


Fig. 11.—SECTION THROUGH SPANISH TILING

Abutments

The best finish at abutments is without doubt provided by soakers and lead flashings. Architects prefer, however, to have as little lead as possible visible on the roof,

Fig. 12.—VALLEY TILING

Fig. 13.—A LACED VALLEY

and the fashion has spread of having a tile flaunching or tile flashing instead of the stepped flashing. Where this form of construction is adopted the tile flashing must be let into a chase : if this is not done, and roof settlement occurs, the tile fillet will come away from the wall, and water will penetrate the gap so left.

Soakers and lead flashings are best from a constructional point of view : in all cases soakers must be inserted, whether a lead flashing, tile flashing, or cement fillet is used. Cement fillets are not recommended.

Vertical Tiling

Plain tiles are frequently used as tile hanging, partly because they give an attractive appearance to an elevation, and partly because tile hanging is the most effective waterproof covering for a wall. Tile hanging, properly carried out, is the perfect damp-resister.

For vertical tiling each tile must be secured with two nails : in fact, complete nailing should be done on all pitches over 55°. Walls may be battened or the tiles may be nailed direct to the joints of brickwork. Since water runs easily off vertical tiling, the lap is not important, and a $4\frac{1}{2}$-in. gauge may be used. This is convenient where the tiles have to be fixed directly to the joints of brickwork on edge.

SINGLE-LAP TILING

The kinds of single-lap tiles are so numerous that it is not possible here to do much more than mention the general principles underlying the covering of a roof with any kind of single-lap tile.

Roof Pitches

For single-lap tiling, roof pitches in general may be slower than for plain tiling, owing to the larger size of the units and the more effective lapping at side and head. A minimum of 35° is recommended, even though in practice slower pitches are seen.

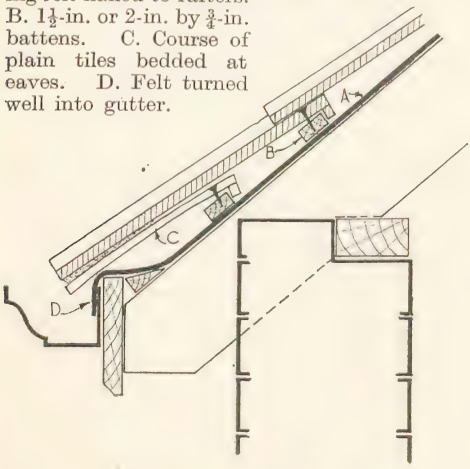


Fig. 14.—CONSTRUCTION OF EAVES IN SINGLE-LAP TILING

A. Untearable roofing felt nailed to rafters. B. 1½-in. or 2-in. by ¾-in. battens. C. Course of plain tiles bedded at eaves. D. Felt turned well into gutter.

Fig. 15.—COURTRAI-DU-NORD TILING ON OPEN BATTENING

Showing method adopted to ensure that the rolls of the tiles run in straight lines from eaves to ridge. (*Langley London Ltd.*)

Roof Preparation

Nearly all forms of single-lap tile require a continuous covering—boards or felt—between them and the rafters.

The ideal roof preparation is that recommended for plain

tiling, namely, plain boards, felt, counter-battens, and battens. When for reasons of cost this is impossible, then a satisfactory and reasonably inexpensive substitute is provided by untearable felt and battens. The felt should be allowed to sag slightly, but only slightly, between the rafters, and must always be carried well over the fascia and turned into the gutter. The sagging provides a series of channels down which any water that may penetrate the joints of the tiles can run to the eaves.

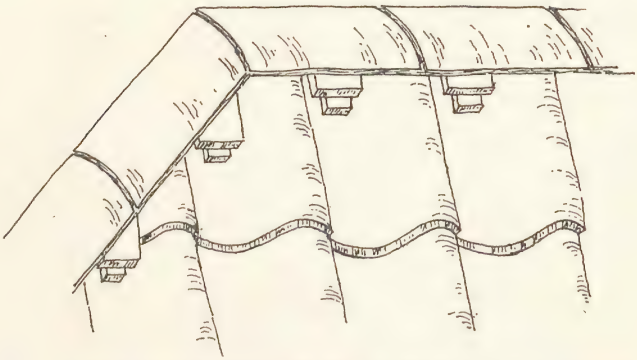


Fig. 16.—TILE LAMINATIONS FITTED BETWEEN ROLLS AT RIDGES AND HIPS

For Spanish and Italian tiling special preparation is necessary. The size and spacing of the vertical battens vary in different makes, and the maker's instructions must be followed. Fig. 11 is a typical section through a roof covered with Spanish tiles. The under tiles are nailed to the sides of the vertical battens, and the upper tile is fixed by a nail driven through the hole provided at the head of the tile.

Eaves

The general construction at eaves in single-lap tiling is illustrated in Fig. 14. A course of plain tiles is usually fixed over the fascia, and the first course of tiles bedded on it. No course of plain tiles is fitted at the eaves of the roof shown in Fig. 15. The tile used, a Courtrai-du-Nord, has only a small roll, and a good length of flat surface to rest on the fascia. With a pan tile, or any other large-roll tile, the course of plain tiles is essential.

Verges

An undercloak should always be fitted at verges: this is even more necessary than in plain tiling. With certain makes of single-lap tile, double-roll tiles are provided for use at left-hand verges. These have no constructional value, but the appearance of the verge is improved by their use. Unfortunately, the length of roof is not always such that a double-roll tile can be used and give the correct overhang at the verge.

Ridges and Hips

The normal type of ridge and hip covering is the half-round ridge. Where a single-lap tile that shows a series of rolls and deep channels is

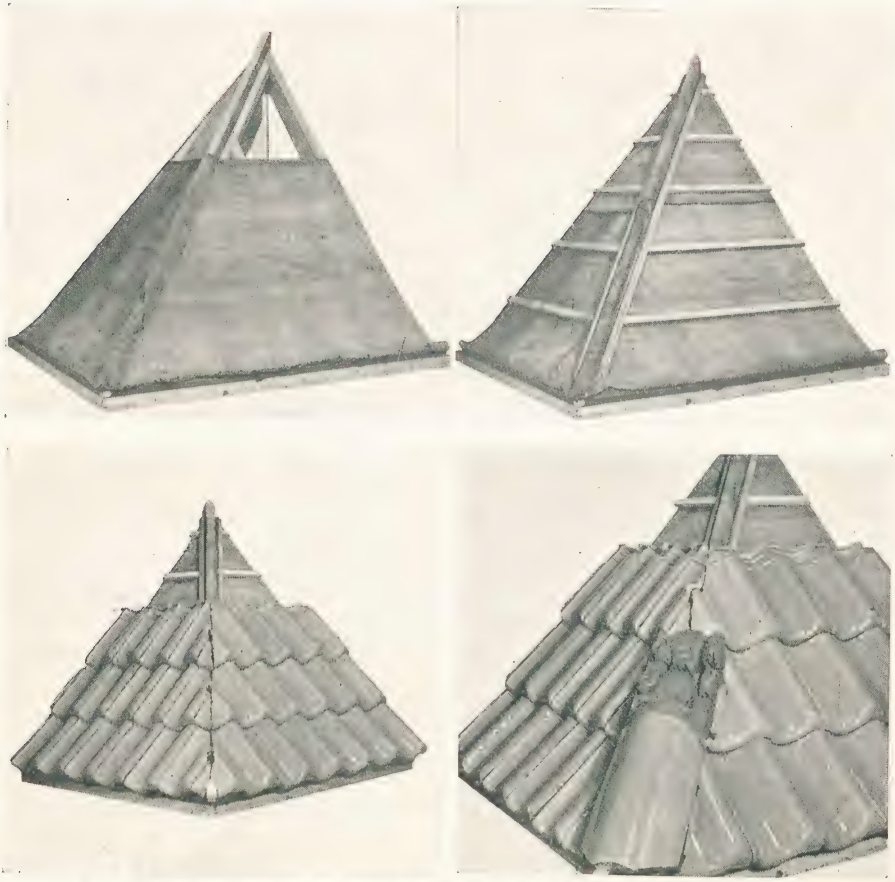


Fig. 17.—FOUR STAGES IN THE COVERING OF A HIP IN SINGLE-LAP TILING
(*Langley London Ltd.*)

used (for example, a pan tile, or Spanish or Italian tile), tile laminations are inserted at ridges and hips to avoid the showing of large masses of mortar (Fig. 16). With pan tiles only two laminations are possible, but with Spanish and Italian tiling three or more may be used. Fig. 17 shows the four stages in the completion of a hip in single-lap tiling. Note that the felt is well lapped at the hip, that it is turned over the fascia so as to come well into the gutter, and that battens run parallel to the hip on each side to give a good fixing for the splay-cut tiles.

Valleys

Where single-lap tiles are used it is better to avoid valleys altogether. The single-lap tile does, in fact, appear at its best on large four-hipped or

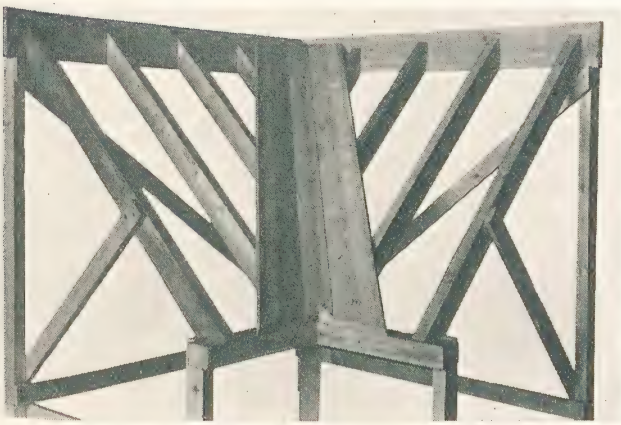


Fig. 18 (*Left*).—VALLEY CONSTRUCTION IN IMPROVED INTERLOCKING PAN TILES —FIRST STAGE

Valley boards fixed. (*Langley London Ltd.*)

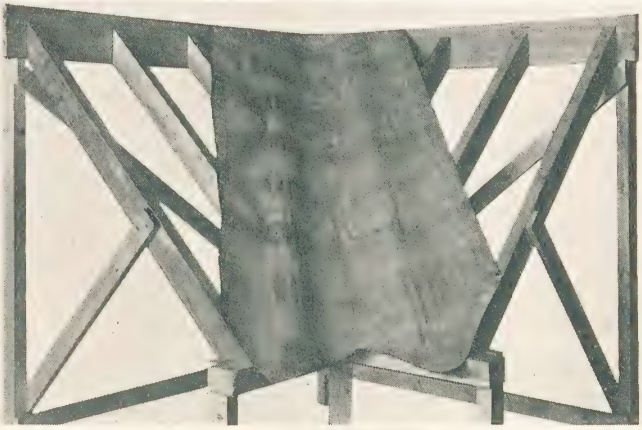


Fig. 18A (*Right*).—VALLEY CONSTRUCTION IN IMPROVED INTERLOCKING PAN TILES —SECOND STAGE

Untearable roofing felt nailed to rafters. (*Langley London Ltd.*)

Fig. 18B (*Left*).—VALLEY CONSTRUCTION IN IMPROVED INTERLOCKING PAN TILES —THIRD STAGE

Felting in valley completed. (*Langley London Ltd.*)

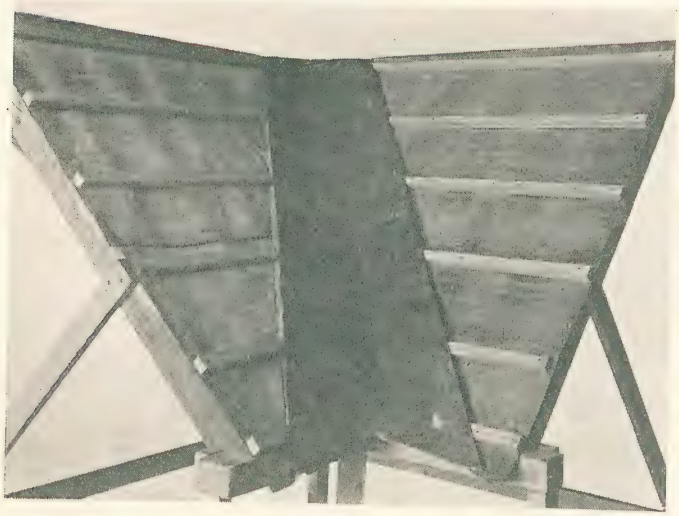


Fig. 18C.—VALLEY CONSTRUCTION IN IMPROVED INTERLOCKING PAN TILES — FOURTH STAGE

Battens fixed on felt and lead valley fitted. (*Langley London Ltd.*)

plain-gabled roofs. Complicated roof plans, and roofs having dormers, are best covered with plain tiles.

Valleys in single-lap tiling are usually of metal, lead being the best material to use. Fig. 18 shows stage by stage the construction of a valley in improved interlocking pan tiles.

A good craftsman should be employed for valleys in single-lap tiling: nothing in tiling is more difficult than to make such valleys watertight.

Fig. 18D.—VALLEY CONSTRUCTION IN IMPROVED INTERLOCKING PAN TILES — FIFTH STAGE

Battening to valley completed. Slate undercloak fitted to valley. (*Langley London Ltd.*)

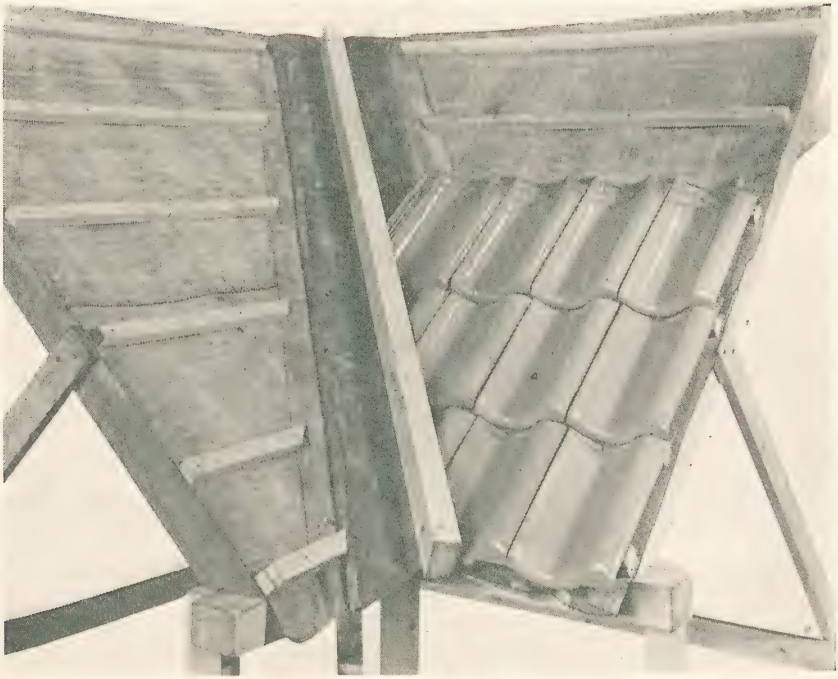


Fig. 18E.—STAGE 6—TILING TO VALLEY
Note precaution to keep edges of valley straight. (*Langley London Ltd.*)

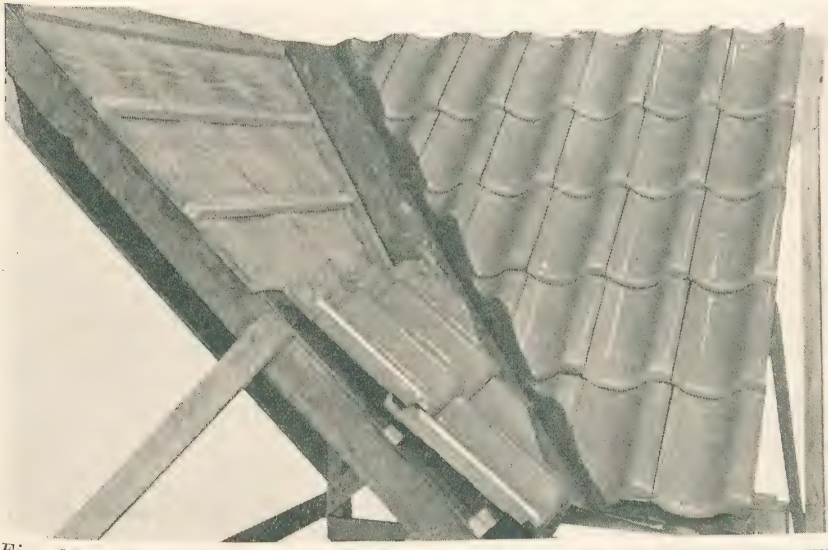


Fig. 18F.—STAGE 7—VALLEY NEARING COMPLETION—STRAIGHT-EDGE REMOVED.
(*Langley London Ltd.*)

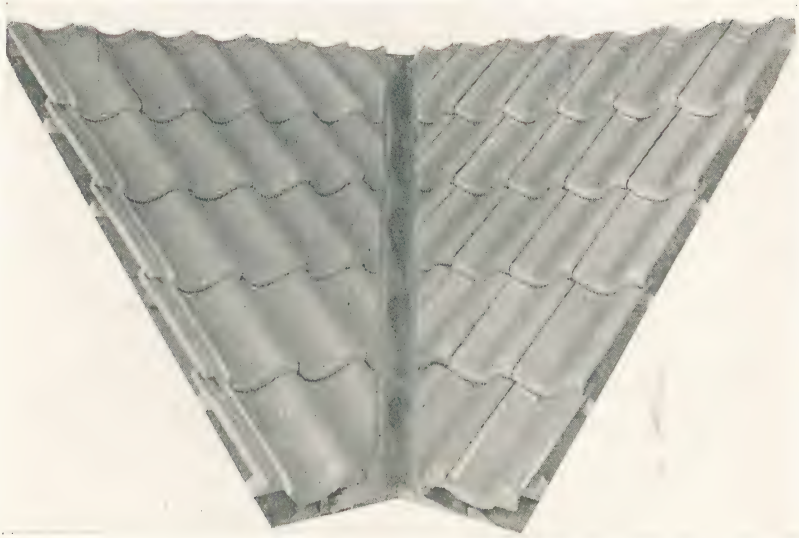


Fig. 18G.—VALLEY CONSTRUCTION IN IMPROVED INTERLOCKING PAN TILES—THE COMPLETED VALLEY. (*Langley London Ltd.*)

QUESTIONS AND ANSWERS

What alternative forms of Roof Preparation for Plain Tiling are adopted in modern practice ?

(1) Open battens.
(2) Feather-edged boards.
(3) Plain boards and battens.
(4) Untearable felt and battens.
(5) Plain boards, felt, counter-battens, and battens.

What are the sizes of Battens for Plain Tiling ?

From 1 in. by $\frac{3}{4}$ in. up to 2 in. by 1 in. A good ordinary size is $1\frac{1}{4}$ in. or $1\frac{1}{2}$ in. by 1 in.

Where should the Gauge be taken from in Plain Tiling ?

From top to top of battens.

What should be the slowest Pitch of any part of a Plain-tiled Roof, excepting hips and valleys ?

Forty degrees pitch.

RUBBER FLOORS

IN this modern age we lean heavily upon the architectural profession to provide us with planned towns and buildings in which to live efficiently, and not the least important part of this problem is the selection of materials which will contribute in every possible way to communal wealth. The search for the ideal floor is never ended, but the comparatively young rubber industry has provided a material which is definitely the floor of to-day and to-morrow.

When it is realised that a floor receives 90 per cent. of the wear to which any interior is subjected, it will be seen that much greater care than usually given should be accorded the selection of a suitable material.

With their unique advantages, rubber floors are established to-day in the same structural category as marble, etc., and are considered to be permanent floors as distinct from floor coverings. The following paragraphs form a practical survey of this material in great detail, and from a point of view not hitherto published.

Definition and Description

There are two distinct forms of rubber floors :—

(1) " Solid " material, in the form of sheets, known in the trade as either (*a*) " flooring," which is made and finished on a drum, or (*b*) " tiling," which is usually the same basic material, but finally manufactured under enormous hydraulic pressure, and given a smooth, impervious surface. It will be understood that " tiling " is thus not necessary in the form of tiles.

(2) " Plastic " material. This is the raw rubber in the form of latex (liquid which exudes from *Hevea brasiliensis*), in conjunction with fillers, cement, etc., with or without an aggregate, and trowelled or floated in jointless form.

Manufacture.—Solid Floors

Coagulated latex, in the familiar forms of smoked sheet or pale crêpe, is milled or softened between horizontal revolving rolls which run at unequal speeds. This treatment tears and then plasticises the rubber until, after about twenty minutes or so, it revolves on one roll in a warm, plastic mass. To this are added various fillers, not as popularly conceived to adulterate or cheapen, but with definite intent to contribute to the various attributes of the finished product.

Obviously, rubber of the consistency of a baby's teat would be quite unsuitable for, say, a tyre tread or a rubber floor, and thus these ingredients, correctly proportioned, increase the resistance to abrasion and ageing to an amazing degree.

Colouring matter, in the form of organic dye-stuffs or in a few cases inorganic pigments, is added until the whole is a uniform shade. The material is then sheeted on a calender, or, if a marbled flooring is required, various colours are run together in a predetermined sequence, first on the rolls and finally in the calender, to obtain the unvulcanised sheeting.

Vulcanisation

One of the fillers added during mixing is sulphur, which is the agent of "vulcanisation." This implies conversion of the soft plastic flooring into the finished product on the application of heat. Material which must be made in a curved or shaped form, e.g. for nosings, is given a short "heat," and is then ready for manipulation upon wooden formers and final vulcanisation.

"Flooring" is processed by vulcanising the sheeting, as it comes from the calender, on a large drum between tightly compressed cloth. The finished material is thus liable to curl and is not of even gauge throughout. It is, however, extensively employed where such points are not of importance.

"Tiling" comes from the calenders in exactly the same way, but is finally vulcanised between the smooth platens of a heavy, hydraulic press. This material has great possibilities and is thoroughly uniform in gauge, ensuring perfect accuracy when designed floors are laid. Only "tiling" or "press-finished" material should be specified or used in the installation of designs.

Thicknesses generally used are:—

Flooring. $\frac{1}{8}$ in.—for light duty, domestic work, etc.

Tiling. $\frac{3}{16}$ in.—for staircases, offices, and the like.
$\frac{1}{4}$ in., $\frac{3}{8}$ in.—for public traffic.

Solid-rubber Floors Should Be of Same Colour throughout Their Thickness

It will be seen that all solid-rubber floors should be of the same colour throughout their thickness, and any material which is offered with a backing, either of black or of self-coloured rubber, textile, or the like, has obviously only the life of the upper coloured flooring.

When Backing Is Permissible

Only in special circumstances should such backing be employed, and that is when an unusually intricate design, in small pieces, precludes really accurate laying at the site, when it is sent out "built up" on a backing from the factory.

Underlay of Rubber Sponge

Sometimes material in large sheets is laid with an underlay of sponge rubber. Whilst this combination has certain advantages, it has been found that the sponge, under continuous traffic, will tend in time to consolidate, and under compression eventually lose its cellular nature. If perfect sponge were available, however, it is questionable whether such floors would be popular, as they can be somewhat tiring, and yet do not provide much greater silence than the normal flooring or tiling.

Another form of solid material should be mentioned here. After the rubber is mixed it is sometimes required in the form of coving or nosings, on the surface of which are required longitudinal ribs. These sections are obtained by extruding or forcing the rubber through a die of appropriate design, when it takes the shape required. Vulcanisation is then carried out in open steam, or in a steel mould.

Plastic Floors

There are two main types. Firstly, these floors are used as an underlay for solid tiling, or, secondly, as the actual wearing surface. Both have the same basic ingredients—a mixture of concentrated latex in stabilised paste form, with a filler, e.g. *ciment fondu*. This plastic is thrown and trowelled *in situ*, and allowed to set. The wearing surface is usually provided by an aggregate, such as cork granules, vulcanised rubber chips, marble chippings, etc., giving a terrazzo effect. Undoubtedly this development will be of great importance, but as these floors are still in the experimental stage, and liable to failure, it is not proposed to discuss them at greater length.

SOLID FLOORS

The following details and data apply only to solid floors.

Methods of Sale

(1) " Flooring " in roll form, as sold to wholesale houses, large stores, etc., for resale in a similar manner to linoleum.

(2) Complete installations in tiling grade.

Advantages and Applications

The attributes of solid-rubber floors are itemised, together with examples of areas.

(1) Durability and Cost

Undoubtedly this is the most important point of all, and as we have already stated that these floors are classed as permanent ones, it will be realised that their durability is unquestioned. Recommended gauges, see above, have a life of 20 years and upwards. The cost of a floor means cost per annum, and as rubber floors cost initially about half the figure

for terrazzo, marble, etc., their value can be truly assessed in the light of the following table, compiled by the Mellon Institute.

	Per Cent. Loss Due to Wear	*Per Cent. Indentation*
Vitreous Tile	4·57	—
Portland Cement	16·79	—
Rubber	20·59	4·00
Marble	23·18	—
Maple Wood	23·79	—
Cork	45·93	26·70
Oxychloride Cement	50·10	—
Linoleum	56·57	13·60
Asphaltic Composition	80·11	61·90

Examples.—Banks, hotels, cinemas, offices, and public areas.

(2) Appearance

Too often are durability and low cost per annum achieved at the expense of appearance. Rubber floors actually improve in appearance with age, providing they are maintained correctly. Because the material is fast dyed, it cannot fade on account of lack of fastness to light.

Examples.—Foyers, flats, hotels, ships.

(3) Hygiene

Rubber floors do not "dust," and being non-absorbent cannot harbour germs, dirt, or dust. Being waterproof and totally impervious they are cleaned very easily, without danger of filthy accumulations.

Examples.—Hospitals, sanatoria, and the like.

(4) Silence

In nearly all rooms, auditoria, etc., acoustic perfection is important. Air-borne noises, mechanical vibration of structure, or impact sounds all demand cure. Due to the resilient nature of rubber, it offers maximum absorption of impact noise, and very little reflection of air-borne noise. Silence is therefore achieved with comfort, and in conjunction with (3) hygiene, these qualities render rubber floors the obvious first choice for the examples enumerated above. It has been proved that the reduction of noise in offices, etc., results in a definite increase in efficiency.

(5) Decoration

It can truthfully be said that no other floor is as artistically adaptable. In other materials, their very nature limits the effects obtainable. With rubber floors, any design, effect, or colour scheme, ancient or modern, can be reproduced at will. Thus, the creative faculties of the architect are catered for, especially in these days of modernist thought, whilst the functional and actual value of advertising inserts, directional signs or designs, monograms, etc., will be readily appreciated.

Examples.—Flats, corridors, shop entrances, cinema foyers.

(6) Safety, etc.

The foregoing qualities are combined with maximum safety and non-slip conditions, insulation of electricity, retention of warmth, resistance to fire, and ease of local renewal if necessary.

(7) Speedy Construction

Speedy construction is of great importance in these days, and the speed at which rubber floors can be laid is a great convenience. Within a few minutes of being cemented or stuck into position, they are available for light traffic. No waiting is necessary, and no protection of work beyond dust sheets, if work still in progress is likely to be of a dirty or abrasive nature, thus making valuable contribution to planning of work on the site.

LIMITATIONS

(1) Oils, Greases

These materials have a deleterious effect on rubber if allowed to remain in contact with it for any length of time. Accordingly, rubber floors are not advised for garages (although suitable for showrooms, where trays are placed below cars), or in pastry-cook's or bakeries, or in stores near bacon or meat counters.

(2) Heat

Any great heat will prevent adhesion of the cement. No difficulty will be experienced near radiators, small hot-water pipes, or over heating ducts, where the sub-floor does not actually carry hot-water piping.

(3) Complete Exposure

Continuous exposure to the elements, whilst not liable to cause rapid deterioration of the qualities of a rubber floor, will cause surface cracking. Minute hair-cracks appear, due to oxidation, and thus appearance would suffer.

(4) Definite Tear

If appearance is of importance this point should be watched. Rubber will, however, provide the finest floor in, e.g., sports pavilions, laboratories, etc., where finish is of secondary consideration.

HOW TO SPECIFY RUBBER FLOORING

When specifications or builder's quantities are being prepared, it must be remembered that preparation of rubber flooring by the manufacturers means the consideration of shapes, and not just over-all dimensions or super quantities. Statements of areas, foot run of nosings, raking, and cutting are not sufficient to obtain the lowest figures.

The reason is that the floor and its design are laid in separate pieces, cut from rectangular sheets, thus causing varying amounts of waste. Waste can result from either design or actual shape of the area. Linoleum, for example, is purchased in 6-ft. widths, and the consumer has to scheme his areas to the best advantage, with the least possible waste.

Why Plans Are Required

Rubber manufacture offers an advantage over this procedure in that it is customary to make each separate job in the most economical widths, but waste still occurs, and it is this waste that must be assessed and charged for when tendering. Thus, plans are required of all areas, stairs, etc., so that irregularly shaped pieces, design pieces, winders, and circular cutting may be assessed not only in terms of labour in cutting, but in waste involved.

(1) Material for Laying Loose

(*a*) *Flooring in Rolls.* Thicknesses $\frac{1}{8}$ in. and $\frac{3}{16}$ in. One colour throughout. Maximum width 6 ft. (most manufacturers have a maximum of 4 to 5 ft.). Maximum length in one piece, about 25 yd.

(*b*) *Tiling in Runner Form.* Thicknesses $\frac{3}{16}$ in. to $\frac{3}{8}$ in. Contrasting coloured borders. Maximum width as above. Maximum length, about 12 yd.

(*c*) *Runners with Sponge Backing.* Thicknesses, widths, and lengths as above. Sponge can be $\frac{1}{8}$ in. upwards. Available with solid bevelled borders.

(2) Material for Cementing

Tiling quality. Thickness $\frac{3}{16}$ in. upwards. *Dimensions.*—To any area or design, any single piece being not greater than 6 ft. in one direction. *Staircases.*—Should be full covered, unless provided with wells. Thickness, $\frac{3}{16}$ in. upwards. *Dimensions.*—Any width or design. Normal nosing sections. Separate treads, nosings, and risers available, or combined tread and nosing with or without separate riser.

Flat Areas.—State use, type of sub-floor and its condition. Give accurate plans.

State design required, giving general trend. If the manufacturers are required to design, give them details of proposed treatment of the area as a whole. Decide colour scheme, remembering that marbled colours show dirt least of all.

State if laying to be carried out in normal hours. *Prices.*—Tenders are usually given in the form of a lump-sum price for the complete installation. They fluctuate only slightly on raw-material figures, but are affected mainly by intricacy of design and material wasted, i.e. the figure per square yard laid equals the cost of material and labour, etc., plus waste, divided by the net area.

Staircases.—State use, and give plans. This is important for the allowance of material for winders, and where combines are required, for a combine to each landing step. Combined or separate treads, nosings, and risers ? Whilst the former achieve elimination of joints, the latter enable the nosings to be replaced with the minimum of expense.

Decide design. Simplicity suits staircases. *Nosing section:* keep to standard sections, without scotias. Unusual nosings involve the introduction of expensive plant for manufacture.

Prices.—Again lump figures are usually quoted for staircase work. Prices, if figured per square yard, vary within wide limits, but are generally 50 to 100 per cent. more than equivalent figures for flat areas.

Special Notes

All plans must be to scale. If sketch plans are given, all tie sizes for walls, curves, counter fronts, winders, etc., should be recorded, as the manufacturer has to draw these out to scale, before fixing in his shapes in the rectangular sheets. Better still, allow the flooring firm to measure, clearly indicating areas to be covered, and deciding points given above.

Requirements at Site

Solid material stuck or cemented in position obviously requires protection at all edges.

Finishes to Floors

Butting to, or under skirting. Wood or metal fillets at doorways. Cover plates at unprotected points. Against coving (rubber or otherwise).

Finishes to Stairs

Against bottom riser. By rubber or other nosing at top of flight, if stairs not covered. To walls or strings, but not outside balusters.

Sub-floors (Flat Areas)

Wood.—All wood floors are suitable, provided they are not covered with paint, varnish, etc. Old, seasoned floors should be planed or sanded level, all joints and cracks filled with plastic wood. If new boards are specified, and are unseasoned, subsequent warping is bound to occur, which will show in the rubber. Plywood is really the best foundation, providing it is screwed down and of sufficient solidity. All wood floors should be suspended and adequately ventilated. If they are not, the sealing of the wood gives ideal conditions for dry rot, and once the malignant *merulius* obtains a hold, a new floor is the only cure.

Asphalte.—Natural rock asphalte is the ideal floor upon which to lay rubber. It should be given a grit- or slate-dusted finish.

Cement Screed.—Must be suspended and thoroughly dry. Care in

mixing is important to ensure a solid surface. The recommended proportion is 3 : 1 river or pit sand, steel-trowel finished, and allowed to dry for about fourteen days. (This varies on precast.)

Granolithic.—See above.

Tiles, Terrazzo, Marble, Ceramic.—All suitable sub-floors, providing they are suspended and are homogeneous. Care should be taken that the surface is not crumbling, and highly polished material should be roughened with hydrochloric treatment or with carborundum.

Composition.—Magnesite floors are quite suitable providing they are suspended and are not oiled or waxed.

Steel.—A bond between rubber and metal is very difficult to achieve, and generally steel floors are covered with a composition. It is possible, however, with very careful technique, to obtain good adhesion providing the steel is thoroughly pickled, and that it presents a continuous surface, i.e. not interrupted by rivet heads. Care should, however, be generally exercised in such cases.

Note.—Where any of the above solid floors are direct to earth, or even on hardcore and rubble, it is essential to provide a horizontal damp-course in the form of natural rock asphalte (see later).

Sub-floors (Staircases)

Wood.—Requirements as for flat areas. Note that nosing sections should be even throughout. Omit or remove scotias. Badly worn treads or nosings should be replaced entirely.

Stone, Precast, Cement, Terrazzo.—Requirements exactly as for corresponding flat areas. Staircases are, as a rule, suspended, but care must be taken that no dampness is present. Basement flights must be damp-coursed under bottom step, and vertically if wall is one string.

Note.—All nosings, of any material or section, must retain that same section throughout. If stairs are worn, take them down to a new section or remake to the old one.

All Sub-floors—Important

Must be completely and permanently free from dampness ; level, homogeneous, and not covered by dust, lime, paint, varnish, old linoleum, or other coverings. Floors direct to earth should be floated with rock asphalte. In course of construction, screeds can be dispensed with, and asphalte laid. The combination of rock asphalte and rubber floors forms the fastest method of construction for finished work. Waterproofers incorporated in screeding are *not* sufficient to prevent enough moisture rising to cause the rubber to lift. The temptation to cover up old floors or stairs should be avoided because, as with other permanent floors, a true foundation is required.

Final Appearance

All other things being favourable, it is true to say that whatever finish is provided in the sub-floor, it will be repeated in the rubber. Thus irregularities of any kind should be avoided.

LAYING

Elsewhere, instructions are given for the execution of this work, and the most important item to remember is to allow the cement or solution to *dry thoroughly*. This takes from 15 to 30 minutes, depending on atmospheric conditions.

Rubber cement should always be employed, as it is unique in that it remains in plastic state throughout the life of the floor, and does not harden or flake. As, however, all manufacturers maintain staffs of highly skilled layers, and prefer to install their own material, it is rarely that inexperienced men are called upon to lay.

Laying—General Notes

Work that is expected to be laid for 20 years and upwards must obviously be well and truly installed, and conditions at site are an important factor.

(1) Arrangements for commencement of work should be made so that following trades do not interfere with operations, or damage the floor. As a rule, work commences in the middle of an area or design and continues outwards, trimming at skirtings.

(2) As skilled men are employed, rates are fixed per hour, with appropriate allowances for overtime or night work.

(3) The convenience of rubber floors is very often abused to the extent that work is sometimes expected to proceed in areas where there is great congestion of other trades. This only hinders and cuts down laying speed. A clear area is definitely required—the contractor can recommence work on it immediately laying is completed.

(4) A very elementary point, but one which is not often appreciated, is that although the adhesive is allowed to dry, it cannot be walked upon by all and sundry.

(5) Note that the solution is highly inflammable, and every precaution should be taken accordingly.

(6) Laying speed. This varies greatly, depending on design, site conditions, and the like. A fair average is $\frac{3}{4}$ hour per square yard, including all incidental work, such as cutting in, arranging design, and labouring rolls to various rooms.

(7) Sub-floors should be cleaned and dusted in readiness. Rubber cement will not adhere to a dusty surface, any more than a gummed label will adhere to dusty paper.

Maintenance

Even under the most difficult conditions, rubber floors are dustless in themselves, e.g. in gymnasiums, and as they are also waterproof, maintenance is extremely simple. For at least three to four weeks after the floors are laid they should not, if it can possibly be arranged, be cleaned at all. The object of this is to allow the floor to " settle down," and also to allow the natural wax present in it to bloom to the surface and thus form a skin or protective layer. It is this bloom which gives rise to the specification sometimes met which states " to be self-polishing."

Following this period, maintenance consists of daily washing with ordinary soap and water—cold or slightly warmed. If any difficulty is experienced it is permissible to employ a cleanser that is definitely non-abrasive—there are several proprietary brands available.

Preferably, however, the floor should be polished. This does not mean that a slippery floor will result, providing a wax polish is used. Anything with a turpentine base should not be employed. After two or three months the floor becomes noticeably brighter, and gradually the brilliance of the colouring increases. Polishing assists the natural wax in providing the skin, helping to retain an immaculate surface.

It will be found that all reputable manufacturers issue maintenance recommendations, which may differ in detail points, and it is best to follow their suggestions.

SPECIALISED USES

Dado

The use of rubber flooring for dado work is increasing. The advantages of a material which will withstand heavy knocks, and which will not crumble, are obvious in such a position. Thickness used is usually $\frac{3}{32}$ in. As with wallboard, rubber needs support from fillets, dado rail, and skirting, as its weight precludes the use of adhesive alone. Cover fillets can be spaced fairly widely, however, providing the rail and skirting are well rebated and fixed. Again, brilliant colouring is available. Designs are built up if required, but this means thicker material ; if, however, anything in the nature of a mural is required, no doubt adequate support could be arranged.

Skirting

Similar advantages are applicable to rubber skirting. Providing a good cement key is given, a successful job can be made and one which will not harbour dust, etc., or warp.

Table and Counter Tops

Flooring material is being used with great success for these tops. It is important to note that all edges should be protected and secured by rebated fillet or metal trim.

Flooring Mats

Installations are often completed with the inclusion of advertising mats. Alternatively, mats are sometimes employed, e.g. in front of a bar, where other types of floors are already in existence.

Druggets

The adaptability of rubber flooring is well illustrated in this application. For the protection of carpets and other valuable materials a rubber drugget is ideal. It is flexible, can be rolled up easily, is washed with ease, is available in a colour to tone with the carpet, and will give unlimited service.

Coving

Although not strictly rubber flooring, coving is an important inclusion where dusty corners, etc., are an objection. Rubber coving is generally 2 in. in height and base, and can be laid against most wall surfaces.

Recent Developments

Most of the development work to-day is centred in the plastic material. As previously mentioned, this is still in the experimental stage, inasmuch as some installations have been successful, whilst others in apparently the same conditions have failed. The main quality claimed for these floors is that they can be laid on any sub-floor, whether suspended or not, and are unaffected by rising damp. Again, as to the final wearing surface they have still to prove their worth, for in spite of the addition of aggregate they are found to indent to some extent.

Apart from plastic floors the main problem exercising the ingenuity of manufacturers is the possibility of discovering a material which will enable the contractors to dispense with the comparatively expensive rock asphalte, where solid floors are direct to earth.

Recently a big demand for rubber floors has been experienced in the following :—

Flats

The recent tremendous activity in the building of blocks of flats has proved the wonderful advantages of rubber floors to the hilt. They provide the solution to the great problem of sound-insulation, whilst speed in installation has contributed largely to the speed of the whole construction.

Building Estates

Much of domestic building to-day is of a speculative nature, and the two rooms, bathroom and kitchen, furnished by the builder, go a long way to making a sale. With rubber floors, property values are increased.

Cinemas

With the obvious advantages of silence, durability, and decoration, rubber floors are employed in cinemas in ever-increasing quantities.

Shipwork

Here, again, the same advantages have caused rubber to be preferred for shipwork. A special feature which is employed here to great advantage is flexibility. The vibrations and stresses in a vessel preclude the use of rigid materials and cements, whilst the waterproof, fire-resistant, and non-slip properties of rubber are employed to the full.

Hospitals

The suitability of rubber floors for hospitals has already been indicated. Such material is now almost a standard for corridors, ward centres, X-ray rooms, etc., where hygiene, silence, and insulation are of great importance.

Churches

The modern trend in ecclesiastical architecture has been followed in interiors. The achievement of silence in such edifices without the loss of dignity is possible in a suitably designed rubber floor. Where both speech and music are heard, short-path reflection of sound is thus obtained, to the general improvement of acoustics.

Selection of Material

The following is a copy of a specification drawn up by the India Rubber Manufacturers Association.

Specification for Rubber Flooring

(1) *General*

The rubber used in the flooring must be uniform in composition, free from ground vulcanised rubber or other forms of ground waste, and the flooring shall not show sulphur bloom, porosity, or any other manufacturing defects.

(2) *Thickness*

The minimum thickness of the flooring shall be :—

(1) $\frac{3}{16}$ in. for general purposes.
(2) $\frac{1}{8}$ in. for light duty.

(3) *Minimum Rubber Content*

The minimum rubber content shall be 25 per cent. by volume of high-grade new rubber.

(4) *Hardness Test*

The hardness shall be measured by the Pusey & Jones Plasto-meter. The reading shall be between 32 and 80 (a $\frac{1}{8}$-in. ball to be used).

The test samples shall have a minimum thickness of $\frac{1}{8}$ in., and a minimum area of 1 sq. in.

Test samples having a rough base shall be buffed smooth.

All tests shall be carried out on a smooth steel plate of a minimum thickness of $\frac{1}{4}$ in.

(5) *Durability*

A strip of the flooring, 6 in. by 1 in., shall be cut and suspended in the usual ageing oven maintained at 70° C. $\pm$ 0·5° C. for a period of three days.

After cooling at least one hour the strip shall be bent so that the two ends come together. These two bends are then clamped with two pieces of iron which can be screwed together for a distance of $1\frac{1}{2}$ in. from the ends of the rubber strip, thus bringing the two faces of the rubber together for $1\frac{1}{2}$ in.

The sample shall be left in the clamp for six hours, and no cracking or breaking shall take place.

Qualities to be Looked for

It will be realised that this specification offers wide limits for the manufacture of material and the properties of the consequent product.

The following qualities should be looked for :—

(1) Colour and design " right through." No backing material, textile, or jointing rubber of a different quality should be accepted.

(2) For installation work, only tiling quality is suitable. This has a glossy " press finish," and may be either smooth both sides or slightly roughened on one side to obtain good key for the adhesive.

(3) The flooring should have a firm, solid feel, and should not be flabby or soft. The uninitiated would probably consider softness as ideal for a floor with consequent silence and comfort. The result is, however, shorter life and stretching and lifting.

(4) The bending or flexing of rubber flooring is *not* a test as to its suitability. Rubber floors are manufactured flat to be fixed flat, and where curved material is required, it is specially shaped for that purpose. No one would consider bending a piece of linoleum double as a test of its suitability.

Selection of Contractor

Rubber-flooring installations should be entrusted only to firms of repute and long standing in the trade, who have examples of their work in all kinds of situations to offer for inspection. Suitable contractors are those who :—

(1) Maintain a specialist department for the work, with an expert who is able to co-operate and advise at the time of specification, and subsequently superintend the installation right through.

(2) Measure any work required and submit suggested designs in colour to any requirements of the architect.

(3) Submit tenders for the work complete, together with guarantee if required.

(4) Maintain their own specialist laying staffs, and arrange to co-operate at progress meetings, in the interests of the general contractors and the job.

(5) Clean and leave the site with sanction of their inspector, who obtains a satisfaction note from the general foreman.

(6) Offer complete after-sales service, advice, and maintenance recommendations.

QUESTIONS AND ANSWERS

What are the two distinct forms of Rubber Floors ?

(1) Solid material in the form of sheets, either (*a*) " flooring," which is made and finished on a drum, or (*b*) " tiling," which is usually of the same basic material, but finally manufactured under enormous hydraulic pressure and given a smooth, impervious finish.

(2) " Plastic " material. This is the raw rubber in the form of latex, in conjunction with fillers, cement, etc., with or without an aggregate, and trowelled or floated in jointless form.

What Material should be used in the installation of Designs ?

" Tiling."

What are the Thicknesses of Solid Rubber generally used ?

(1) Flooring material—$\frac{1}{8}$ in., for light-duty domestic work, etc.

(2) Tiling—$\frac{3}{16}$ in., for staircases, offices, and the like ; $\frac{1}{4}$ in. and $\frac{3}{8}$ in., for public traffic.

How are Solid Rubber floor materials sold ?

(1) " Flooring " is sold in roll form to wholesale houses, large stores, etc., for resale in a similar manner to linoleum.

(2) Complete installations are sold in the tiling grade.

How long may a Rubber Floor be expected to last ?

A life of 20 years and upwards may be expected for a rubber floor consisting of the grades recommended above.

What are the maximum Widths and Thicknesses of Flooring supplied in Rolls ?

For thicknesses of $\frac{1}{8}$ in. and $\frac{3}{16}$ in., most manufacturers have a maximum width of 4 to 5 ft. In some cases a maximum width of 6 ft. can be supplied. The maximum length in one piece may be about 25 yd.

What are the Widths and Lengths of Tiling in Runner Form ?

Thicknesses $\frac{3}{16}$ in. to $\frac{3}{8}$ in. Maximum width as for flooring. Maximum length, about 12 yd.

How do you specify for Flat Areas in " Tiling " ?

Give accurate plans and state the following :—

(1) Use.
(2) Type of sub-floor and its condition.
(3) Design required.
(4) Colour scheme.
(5) If laying is to be carried out in normal hours.

How do you specify for Staircase " Tiling " ?

Give plans and state :—

(1) Use.
(2) Whether combined or separate treads, nosings, and risers.
(3) Design.
(4) Whether standard nosings, without scotias, or unusual nosings are required.

In what form should the Plans be given when specifying ?

To scale. If sketch-plans are given, all tie sizes for walls, curves, counter fronts, winders, etc., should be recorded, as the manufacturer has to draw these out to scale, before fixing in his shapes in the rectangular sheets. Better still, allow the flooring firm to measure, clearly indicating areas to be covered.

What precautions should be observed before covering Wood Floors ?

They should not be covered with paint, varnish, etc. Old, seasoned floors should be planed or sanded level, and all joints and cracks filled with plastic wood or other suitable filling. If new boards are specified, they should be properly seasoned. The floor should be suspended and adequately ventilated.

What precautions should be observed before laying on Tiles ?

See that the surface is not crumbling. Highly polished material should be roughened with hydrochloric treatment or with carborundum. The floor should be suspended and homogeneous. Where the floor is laid direct to earth, or even on hardcore and rubble, it is essential to provide a horizontal damp-course in the form of natural rock asphalte.

What precautions should be observed before laying on Terrazzo, Marble, or Ceramic ?

Similar precautions should be observed as for tiles.

How should the Laying Work be arranged to ensure the greatest Speed ?

Arrangements should be made so that the other trades do not interfere with operations on the site, or damage the floor.

What is a fair average Laying Speed ?

The laying speed varies greatly, depending on design, site conditions, etc. A fair average is $\frac{3}{4}$ hour per square yard, including all incidental work, such as cutting in, arranging design, and labouring rolls to various rooms.

How is a Rubber Floor best maintained ?

By polishing with a wax polish. After two or three months the floor becomes noticeably brighter, and the brilliance of the colouring gradually increases. Polishing assists the natural wax in providing the skin, thus helping to retain an immaculate surface.

What are the essentials for applying Rubber Flooring to Dado Work ?

(1) A thickness of $\frac{3}{32}$ in.

(2) Support by means of fillets, dado rail, and skirting, in addition to the adhesive. Cover fillets can, however, be spaced fairly widely, providing the rail and skirting are well rebated and fixed.

What are the dimensions of Rubber Coving ?

Generally 2 in. in height and base.

What precautions should be observed with regard to the Adhesive when laying Rubber Flooring ?

(1) Allow the cement or solution to dry thoroughly. This takes from 15 to 30 minutes, depending on atmospheric conditions.

(2) The floor should not be walked on during the drying period.

(3) The solution being highly inflammable, precautions should be taken accordingly.

WOOD FLOOR CONSTRUCTION

PART I.—SINGLE-JOIST FLOORS

THE various types of floors to be considered are as follows :—

(1) *Single-joist Floors.* This type is divided into (*a*) where it is the lowest floor of a building, and (*b*) where it is an upper floor with a span not exceeding 16 or 18 ft.

(2) *Double Floors.* This type includes floors of greater span, where larger members are incorporated to cope with the heavier stresses which are bound to result from the increase in span.

(3) *Framed or Triple-joist Floors.* These are found to be necessary for floors of greater span than " Double Floors " or where the form of loading necessitates the use of more members to ensure the floor being strong enough to support the extra loads with a reasonable margin of safety.

We shall now deal with the construction of single-joist floors.

MATERIALS USED

Joists

The different kinds of timber used for floor joists are dependent on the size of the joists and the class of work expected ; the latter point is, of course, dependent on how much money is available.

Now, for joists of small section, such as for dwelling-houses, the most suitable timber is Northern pine, more commonly referred to as Scotch fir, red or yellow deal or redwood.

This timber is much stronger than the white fir or spruce which is sometimes used where the price is a consideration, and the considerable increase in strength makes the small increase in cost well worth the extra expense.

Douglas fir is usually used where the sections of the joists are larger, and particularly for public buildings, where a good finish is expected without too much worry about the cost.

Why Joists Fail

When we are concerned with floor joists, and the comparative strengths of the different kinds of timber are being considered, it is as well to remember the sort of failure usually met with.

Ignoring failure due to bad ventilation and damp, and considering only failure due to excessive loading :—

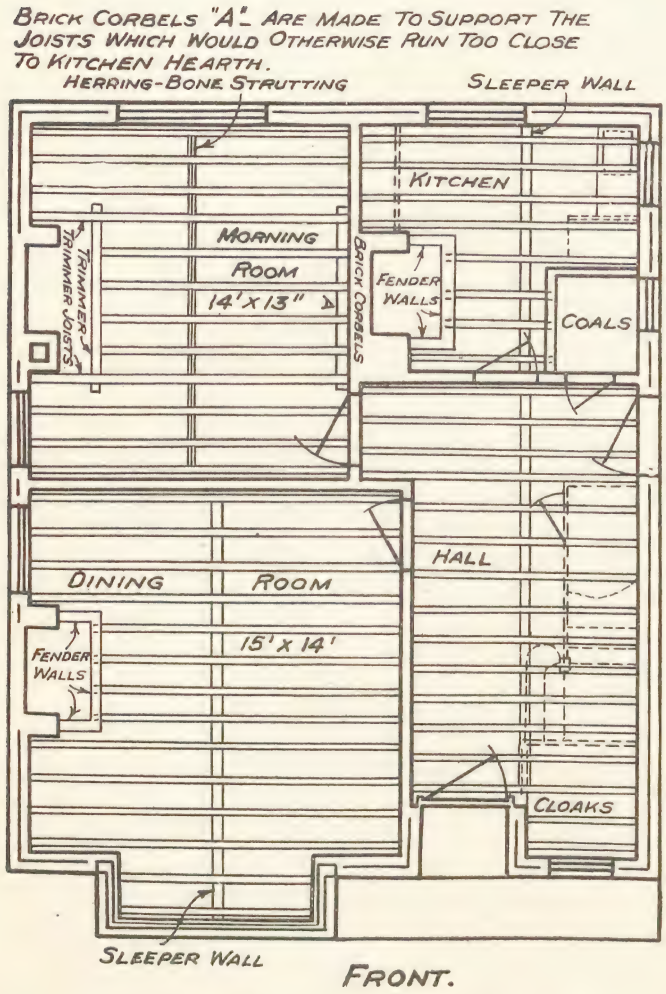


Fig. 1.—GROUND-FLOOR PLAN OF A DETACHED DWELLING-HOUSE

Showing laying of floor joists. The joists for the morning room are trimmed, as this room is over a wash cellar.

The first signs of such failure in a timber floor joist of a span not greater than twenty times the depth of the joist will usually be found to occur about the centre of the depth, where fracture due to tension and a lengthwise split will be seen.

This split is called "longitudinal shear," and certain timbers, which are better than other kinds in resisting this form of failure, are to be preferred.

Floor Covering

For the floor covering, the various timbers available cover a wide range, starting with white deal or spruce for the cheaper work and including red deal and the hardwoods, such as beech, oak, and maple, in blocks or boards, according to the type of floor concerned.

Building Regulations with Regard to Floors

The regulations laid down by the governing bodies of different areas vary slightly, according to the leniency of those who compile them, but the principle amounts to the same in all cases. The following are one or two of the more important items which affect us if we are working in the London area :—

Timber work shall not be placed—

(*a*) In any wall or chimney breast nearer than 12 in. to any flue or chimney opening.

(*b*) Under any chimney opening within 10 in. from the upper surface of the hearth of such chimney opening.

(*c*) Within 2 in. of the face of the brickwork or stonework about any chimney or flue, where the substance of such brickwork or stonework is less than $8\frac{1}{2}$ in. thick, unless the face of such brickwork or stonework is rendered.

Also, the Ministry of Health states that—"No timber plugs are to be inserted within 6 in. of any flue."

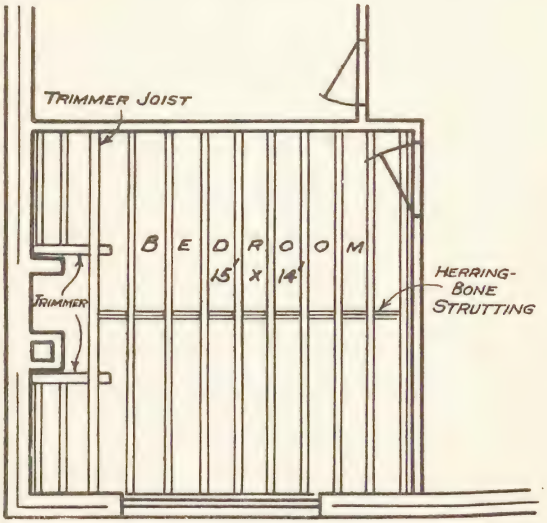


Fig. 2.—PART FIRST-FLOOR PLAN OF DETACHED DWELLING-HOUSE

Showing bedroom over dining-room, seen in Fig. 1. Here the joists run parallel to the chimney breast, which is an alternative to the morning-room in Fig. 1.

Variations that may occur in the regulations of different areas are mainly in the amounts of the above clearances, but it should be clear from the few items mentioned that these regulations are precautionary measures and are not merely red tape.

Calculations

There is a number of calculations in connection with the dimensions of the floor joists used for different spans and various loads to be provided for in any floor, but as the data for sizes, etc., are given later, it is not necessary to deal with the matter here.

LAYING FLOOR OF SMALL DETACHED HOUSE

So, taking it for granted that the materials are at hand, we will start with an example of a small detached house, which is to have the floor laid on in the usual way, i.e. as the job progresses.

During this example we will look over the different methods of supporting the ends and the usual joints which are regularly used, as well as those which are seldom used on such small work as the example under consideration.

On account of the falling ground on which this detached house is built, a cellar is placed under the back room to utilise the space which

would otherwise have been wasted. The floor of this cellar is of concrete, as it is to be used for washing purposes, and all that need be said about it is that the proper damp-proofing course must be used, either in or on the surface of the wall, vertical and horizontal, as well as a layer of bitumen between the two layers of concrete forming the floor.

It will be seen from Fig. 1 that some of the floors are on the sleeper and fender walls. Therefore they need not be trimmed. But those over the cellar will require trimming, as will also the bedroom joists. We will deal with these later together, although they will be fixed whilst the work is at their respective levels.

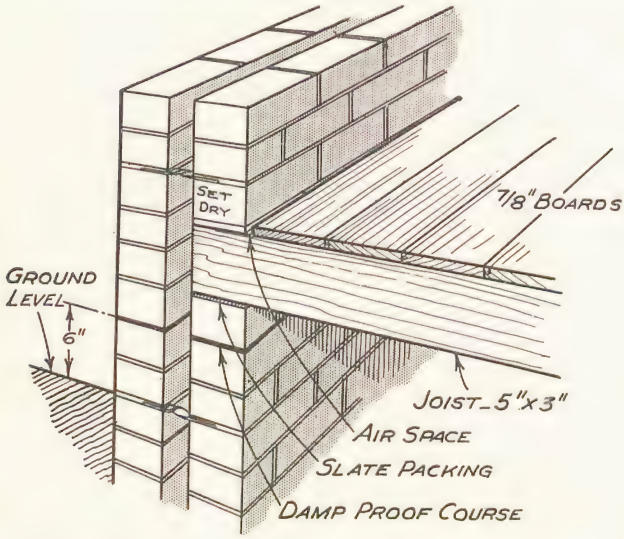


Fig. 3.—FLOOR JOISTS LEVELLED WITH SLATE PACKINGS

What Is Meant by Trimming

Trimming means the framing of the joists to form an opening in the floor or ceiling, as the case may be, such as a manhole, well-hole for stairs, etc., and also to avoid running the ends of the joists into the chimney breast. This would bring them dangerously under the fire or close to the flue, even were it allowed by the local authorities.

Run of the Boards

Although it is not always done, if it can be arranged it is much better for all the joists of any one floor level to run in the same direction, so as to avoid joints between the ends of boards of one room with the edge of a board in another room. This would not look very well, and unless this joint were tongued it would be liable to squeak.

The Sleeper Wall

Taking the joists for the dining-room, kitchen, and hall, it will be seen that by having a sleeper wall down the centre of the dining-room and the centre of the kitchen and hall, we shall have our greatest span 7 ft. 6 in., and for this the joists supplied will be 5 in. by 3 in.

If the job is worked as it is commonly done nowadays, the joists will

bear on the brickwork, except where it is necessary to pack them up as shown in Fig. 3 to bring all the top edges level. The joists should be supplied in different lengths to suit their respective positions in the different rooms.

Sorting Out the Joists

The first job is to sort them out accordingly and place the suitable ones in position on the walls. Make sure, if there are any which are not straight, to see that these are laid with what is usually called the " round edge " to the top, so that if any sagging occurs, it will only tend to straighten the joists instead of making the floor hollow on the top.

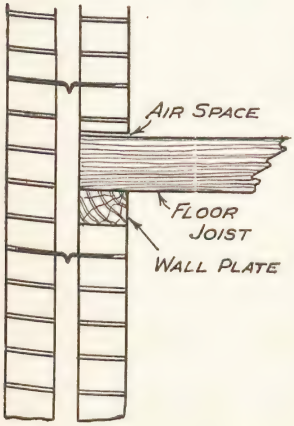


Fig. 4.—FLOOR JOIST SUPPORTED ON BUILT-IN WALL PLATE

Spacing Out the Joists

We must first have one 2 in. or 3 in. from the wall and one 2 in. or 3 in. from the chimney jamb, and then space the others out equally between.

If at first the spaces come more than 16 in. from centre to centre, another joist must be used. It is always better to have the joists less than 16 in. apart rather than more, or sagging of the floor boards will occur unless more than a $\frac{7}{8}$-in. board is used.

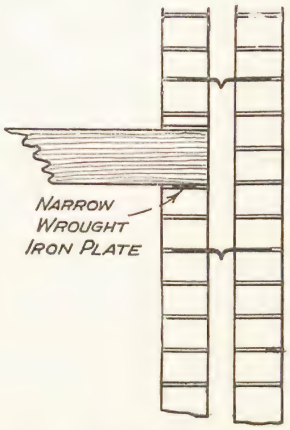


Fig. 5.—METHOD OF SUPPORTING FLOOR JOIST IN WALL ON WROUGHT-IRON PLATE

This being done, a lath should be nailed to the top edges to keep them in place until they are built in by the bricklayer. The bricks adjoining the ends of the joists should be set dry, to prevent, as far as possible, dry rot.

Levelling the Joists

When the joists at this level are all laid on with laths across, a long, straight, and parallel rule should be found and used on the ends of the joists as follows : By going round the building with this straight-edge and a reliable level, the highest point will be found. Then, starting from this point, the joists will have to be packed up to this level where required, with either slate or wood packing. Some prefer wood and others slate, but slate is generally accepted as the best, as it is not so liable to crush

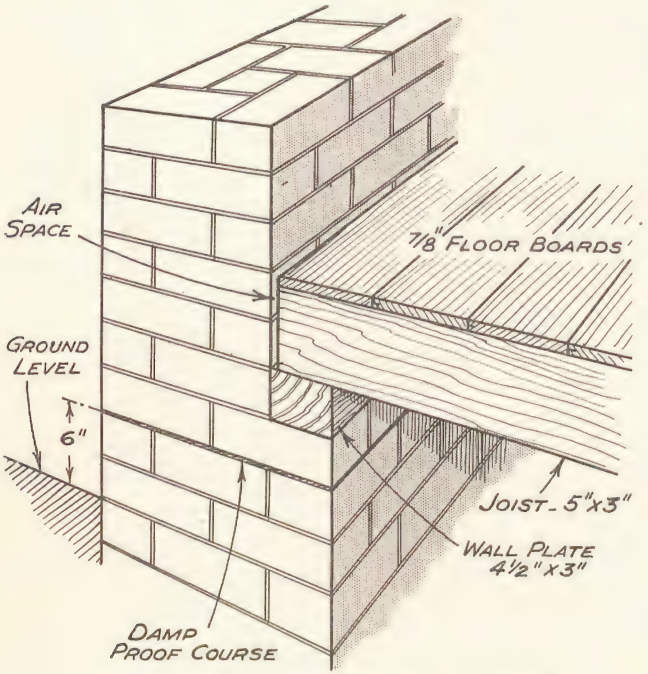


Fig. 6.—WALL PLATE CARRIED ON A SET-BACK

or shrink when drying, for there might be a great variety of thicknesses, and with wood the thicker ones will shrink more, thus causing unevenness in the floor.

We have described only one method of laying this floor, so now we will consider the various ways in which the above method can be improved.

METHODS OF SUPPORTING ENDS OF JOISTS

In Figs. 4 to 8 different methods of dealing with the ends of the joists are illustrated, the method shown in Fig. 3 having already been explained.

Built-in Wall Plate

First of all we will deal with Figs. 4 and 5, where the load, which is put on the walls by the joists, is distributed more evenly over the length of the wall by means of a wall plate in Fig. 4 and a narrow wrought-iron plate in Fig. 5.

The laying of the joists in these cases, and for that matter in all cases where wall plates occur, is on the same lines, so that the following description will apply to the other methods detailed later.

The wall plate or the iron plate, as the case may be, must—before any joists are laid—be set dead level all round the building, and then the rest is straightforward.

Making Joists Level

Joists, as you are no doubt aware, vary in depth, and this difference must be allowed for during fixing. With this object in view the ends of the joists are gauged from the round edge to a depth equal to the narrowest joist, and the remaining portion is notched out where it bears on the wall plate. This will bring all the joists, when laid in position, level on the

top, and they can then be nailed to the wall plate where it is of timber, or secured by laths, as described earlier, where the wrought-iron plate is used.

" Set-back " Wall

The arrangement of the wall in Fig. 6 is known as a " set-back," where the wall below the floor is $4\frac{1}{2}$ in. thicker than it is above, thus providing a ledge for the wall plate to rest on. This is not always or only used on 18-in. to 14-in. walls, the illustration being just one example. The method is usually adopted in the case of buildings larger than the average dwelling-house, such as a warehouse, where a great weight is put on the floors and the walls are half a brick thicker for each additional storey, so forming this set-back at each floor level.

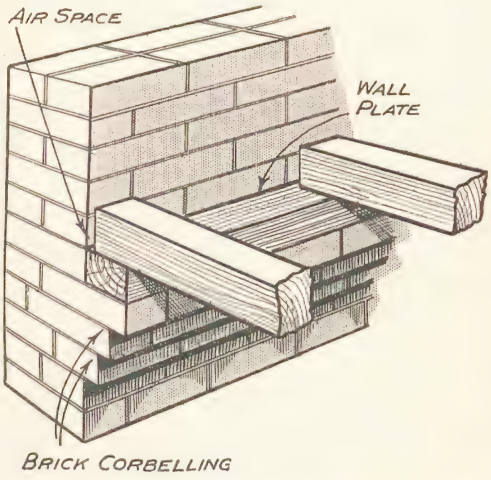


Fig. 7.—WALL PLATE SUPPORTED ON BRICK CORBELLING

It is also done in dwelling-houses and similar small buildings for the ground or basement floors, as it is found to be much stronger for the wall plate to be out of the wall which takes the weight of the building above, for, should the wall plate eventually rot, it would allow the wall to crush it, and settling of the brickwork would result.

Brick and Iron Corbel Supports

In Figs. 7 and 8 two further methods of supporting the wall plate outside the wall are given, the former showing an offset made by corbelling the brickwork out, whilst for the latter, wrought-iron corbels are built into the brickwork every 2 ft. 6 in. to 3 ft. along the length of the wall plate.

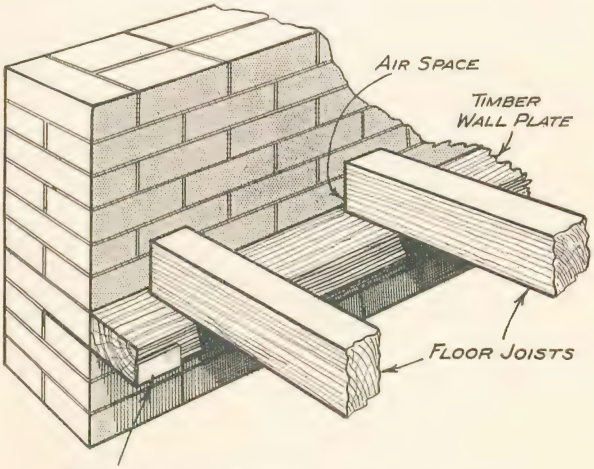


Fig. 8.—WALL PLATE CARRIED ON WROUGHT-IRON CORBELS

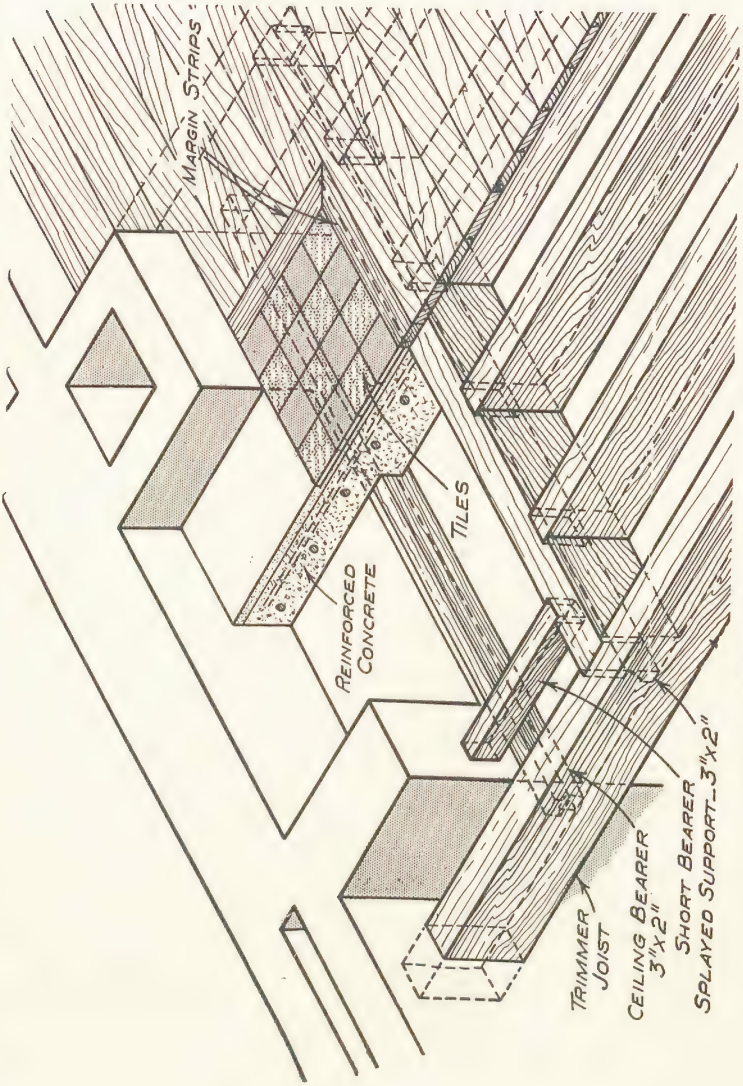


Fig. 9.—ISOMETRIC VIEW OF CONCRETE HEARTH

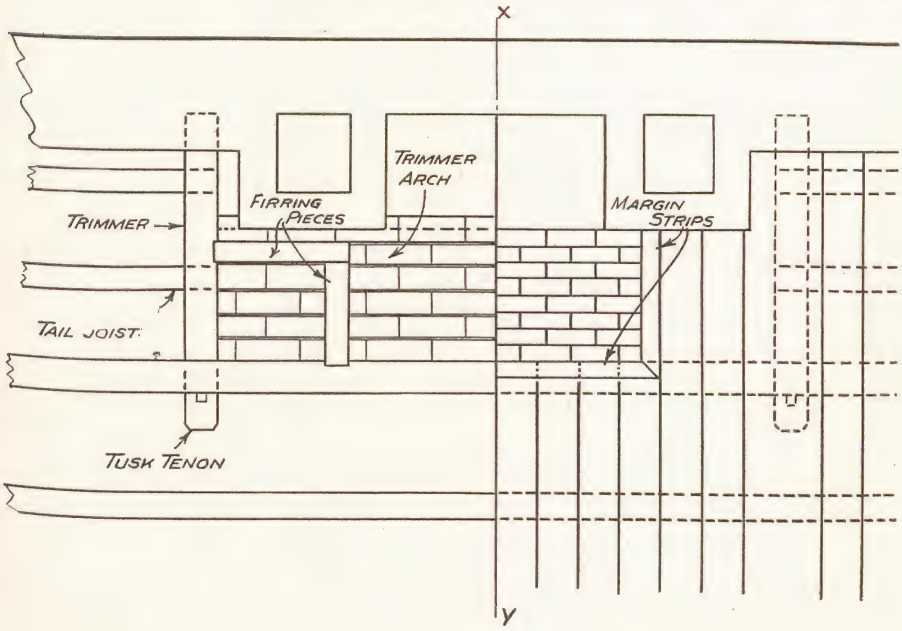


Fig. 10.—PLAN OF HEARTH WITH TRIMMER ARCH

Neither of the two latter methods would be suitable for an upper floor, unless a sufficiently large cornice were used in the room below to cover the wall plate, etc.

In every case where the joists are supported either in the wall or on a wall plate outside the wall, they must be allowed air space all round the ends, and a coat of creosote or other preservative is a further safeguard against dry rot.

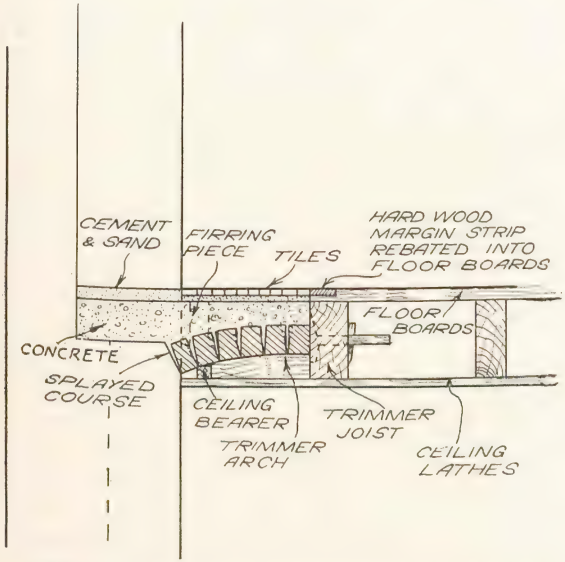


Fig. 10A.—SECTIONAL ELEVATION ON XY, FIG. 10

TRIMMING THE FLOOR FOR THE HEARTH

We will now deal with the floor for the morning-room in Fig. 1 and the large bedroom in Fig. 2. These two floors, as previously mentioned,

differ from those we have just dealt with, in so much as it is necessary to trim the joists round the fireplace now that there is no fender wall.

It will be seen that the joists for the morning-room run in the opposite direction to those for the bedroom, for in the former case the joists are at right-angles to the hearth, whilst for the latter they are parallel to it.

This necessitates two methods of trimming the joists, and these are shown in detail in Figs. 9 and 10.

Joists at Right Angles to Hearth

Considering first Fig. 9, where the joists run at right angles to the breast and hearth.

The two joists which run close alongside the chimney breast are termed trimmer joists, because they support the trimmer which in turn supports the trimmed or tail joists, so that by this arrangement the regulations concerning floor joists running too close to the fire are complied with.

Both the trimmer joists and the trimmer are thicker than the ordinary joists on account of the extra weight they have to carry.

This increase, technically, would be $\frac{1}{8}$ in. for every tail joist they have to support, but usually they are 1 in. thicker than the ordinary joist, and this makes allowance for cutting the timber away when making the necessary joints.

Joists Parallel to Breast

In Fig. 10, where the joists run parallel to the breast, there is one trimmer joist running straight across the front of the hearth at the necessary distance from it to suit the size and style of hearth, which will be explained in detail later.

From this trimmer joist, short trimmers run down each side of the breast to receive the short tail joists which reach between the trimmer and the wall.

These short trimmers and the trimmer joists mentioned in the first case should be set at a sufficient distance from the chimney breast to comply with the local regulations in force.

Trimming Joints

There are other points in connection with the hearth which are to be dealt with in this section, but we will first of all look over the various joints used between the trimmer joists and the trimmer, and the trimmer and the tail joists.

Two types of joints most commonly used in the class of work such as the example being considered are shown in Figs. 11 and 12.

These two joints are known as the square and bevelled housing respectively, and though they are cheap joints, they are considered good

enough for such work as the average dwelling-house.

Square Housing

The main advantage of the square housed joint, Fig. 11, is that it can be easily and quickly made. On reference to the figure it will be seen that only the top half of one joist is let into the other for about one-quarter of the thickness of the one to be housed. A very important point to remember when making most joints, where strength is of first importance, is not to cut too deep.

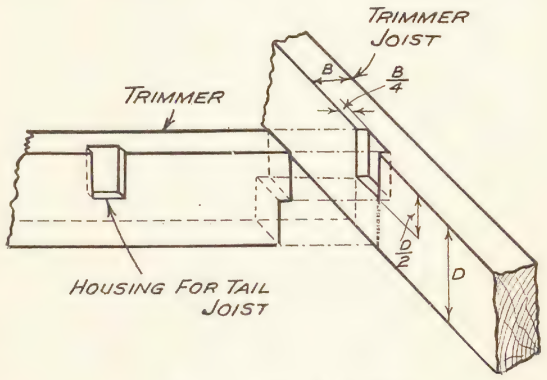


Fig. 11.—SQUARE HOUSING

Bevelled Housing

The bevelled housing, which is sometimes referred to as the splayed housing, is shown in Fig. 12; it is a slightly better job than the first mentioned, as the strength of the joist into which the housing is cut is not affected. Some little explanation of such a statement will be necessary, and as the same theory is concerned with the next joint to be described, we will explain it at this point.

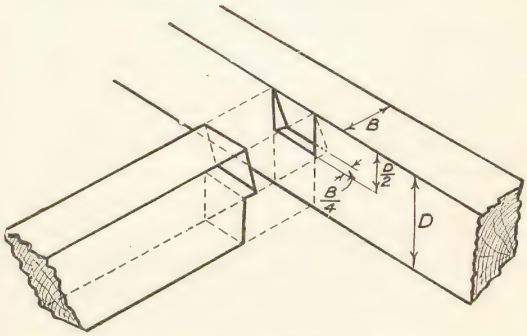


Fig. 12.—SPLAYED OR BEVELLED HOUSING

Position of Housing in Joist

We will first go into one of the reasons for not extending the housing below the centre of the joist.

If we imagine a joist extending across two supports as shown in Fig. 13 supporting a load at the centre of the span

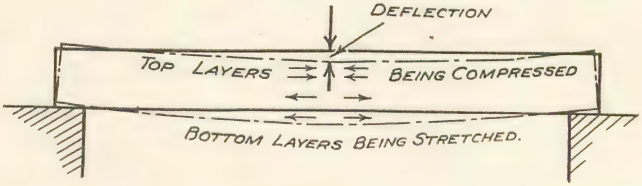


Fig. 13.—WHAT HAPPENS TO A BEAM WHEN SUBJECTED TO A LOAD

Fig. 14.—SECTION OF FLOOR JOIST
Showing limit to which housing should be cut.

as shown, we can expect that joist to have a deflection, and this is shown exaggerated in Fig. 13.

Now it should be clear that this deflection has the effect of shortening or compressing the fibres of the joist on the top layers and stretching the fibres on the bottom layers.

If this is clearly appreciated, it should now be seen that if we remove any material from above the centre of the depth when making a housing in a joist, then when the housed joist is fitted in position and weight is put on the joist the tendency will be for that housed joist to be compressed. Whereas, if the joint were made below the centre, when the load was put on and the resultant stretching due to deflection occurred, the joint would obviously open.

Depth of Housing

So much for the position of the housing. Now we will consider the shape and safe depth of that housing. It can also be scientifically proved that if the cut does not extend into the joist beyond the diagonals shown in Fig. 14, as at A or B, the strength of the joist is not seriously impaired, as far as simple bending is concerned.

This latter point explains why the bevelled housed joint is stronger than the square, and it is also a feature of the tusk tenon, which we will now describe.

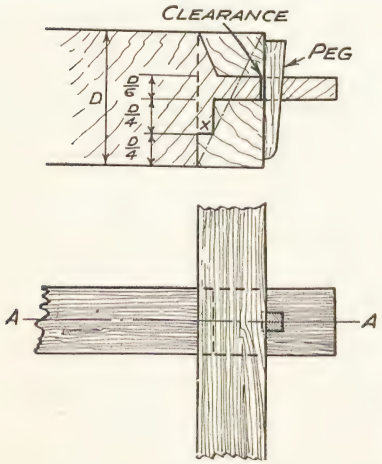


Fig. 15.—PLAN AND SECTION ON AA OF TUSK TENON

Tusk Tenon Joint

In Figs. 15 and 16 the dimensions for the tusk tenon are given. This joint is on a somewhat different principle from the square and bevelled housing, as the end is definitely and rigidly gripped, the design is technically correct, the difference in principle having been given full consideration.

It should be noticed that in this joint, apart from the tenon, no cut goes beyond the diagonals.

The joint is pulled together by means of the peg which passes through the tenon, as will be seen from the illustration.

The tusk tenon joint is a first-class job, and when well carried out will last

for centuries, as will be seen from examination of ancient buildings.

The joints between the trimmer and the tail joists are similar to the tusk tenon, except that the tenon does not project through and therefore cannot be pulled up by a peg.

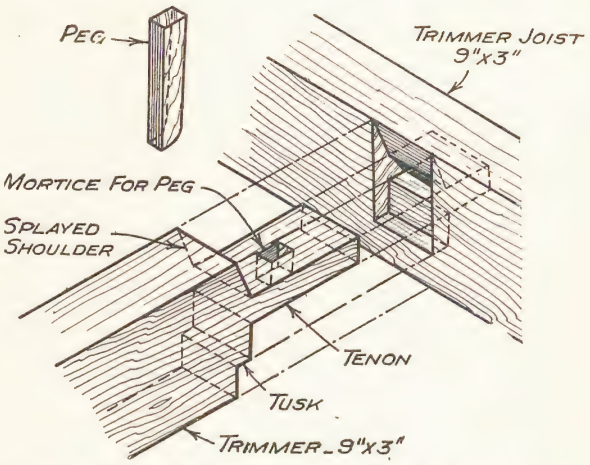


Fig. 16.—TUSK TENON SHOWING TENON WITHDRAWN

STRUTTING

Strutting between the joists as shown in Figs. 17 and 18 gives extra strength to the floor by distributing the load and also stiffening the joists, so helping to prevent cracked ceilings when a severe load is momentarily put on one joist.

Solid Strutting

Solid strutting is shown in Fig. 17, where boards $1\frac{1}{4}$ in. thick and almost as deep as the joists are fitted in tight between the joists and secured by nails driven in on the skew ; the strutting must be continued between the end joist and the wall. This method is very effective for the time being, but no joists used on a job nowadays can be guaranteed perfectly dry, therefore shrinkage will occur and the strutting will become useless. This is not the case with herringbone strutting, for when the joists shrink the struts tend to tighten, as will be seen by reference to Fig. 18.

Herringbone Strutting

Here 9-in. by 3-in. joists are shown at 15-in. centres ; shrinkage in the joists has been suggested as $\frac{1}{8}$ in. for the width and $\frac{3}{8}$ in. for the depth, so that after shrinkage the distance between A and B will be $\frac{3}{8}$ in. less, but the distance between the joists will have been increased only by $\frac{1}{8}$ in., so that tightening of the struts will result.

Fig. 19 gives an isometric view of herringbone strutting, showing the method of cutting the struts.

Cutting Struts for Herringbone Strutting

Two parallel lines are drawn on the top of the joists as shown, their distance apart being $\frac{1}{2}$ in. less than the depth of the joist.

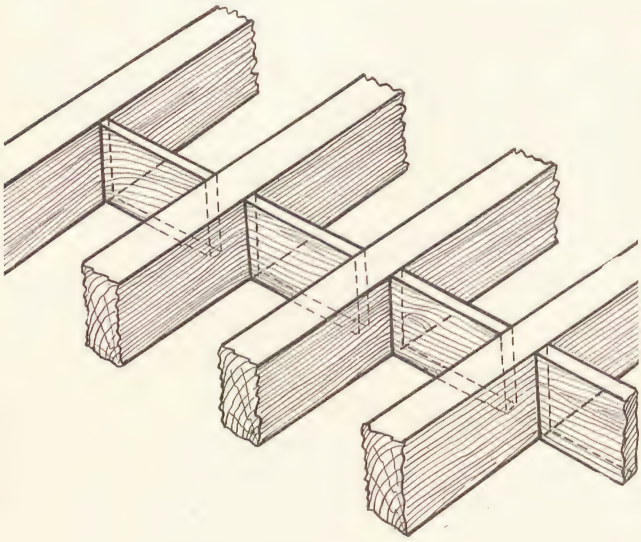


Fig. 17.—SOLID STRUTTING

When the timber for the strutting is laid on the top of the joists, as shown in Fig. 19, and set to the lines as at A and B, it can be marked underneath to the joists, and when cut to these lines the struts will fit exactly between the joists to which they were marked.

Before the struts are secured in position, it is advisable to saw cut down the ends, as shown, so as to avoid splitting when nailing.

CONSTRUCTING THE HEARTH

This can be done quite effectively in a number of different ways, but we will confine ourselves to two methods in regular use.

Reinforced Concrete Hearth

First of all, in Fig. 9 the hearth is of reinforced concrete, more or less cantilevered from the back of the hearth to the front, the front being partly supported on a 3-in. by 2-in. splayed piece nailed to the trimmer and trimmer joists as shown. A piece of 3 in. by 2 in. is run along the front of the breast between the trimmer joists to carry the ends of the plaster laths for the ceiling below. The concrete shuttering for the hearth is kept up about 1 in. from the bottom edge of the joists so as to allow the plaster room to key to the

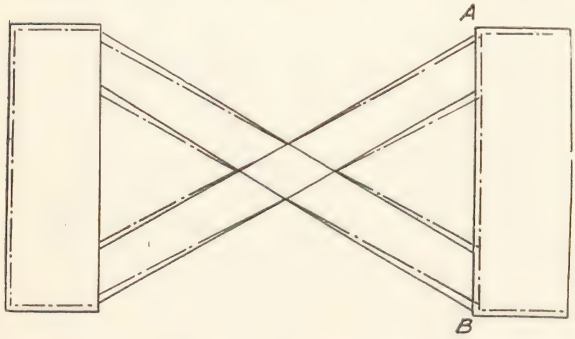


Fig. 18.—HOW HERRINGBONE STRUTTING TIGHTENS WHEN SHRINKAGE TAKES PLACE

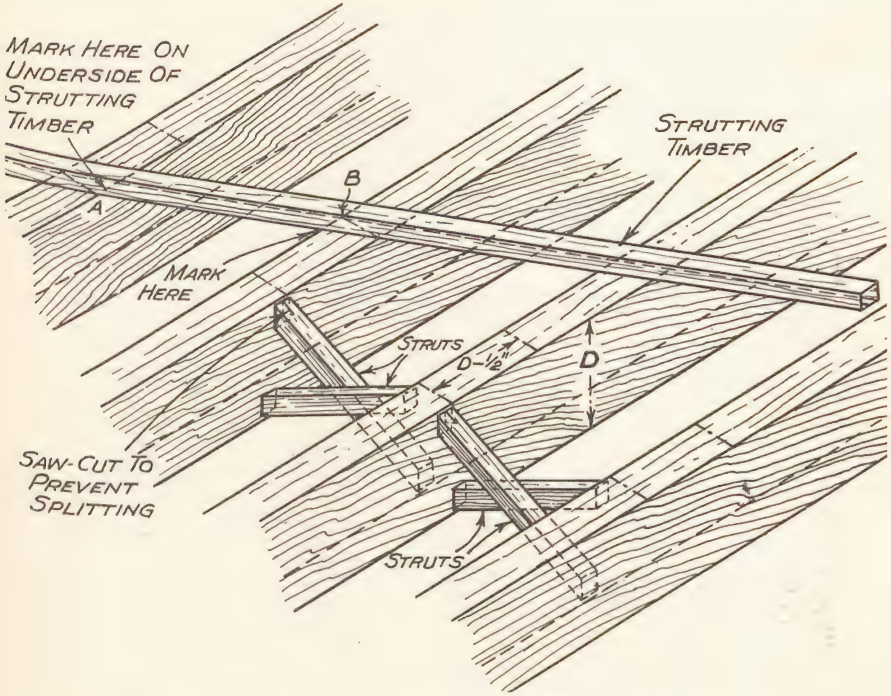


Fig. 19.—METHOD OF CUTTING STRUTS FOR HERRINGBONE STRUTTING

laths which run under the concrete. Sometimes the first course of bricks above the bottom edge of the joists is allowed to " oversail " or overhang, thus forming a support for the concrete outside the fireplace opening along the face of the breast. There are two short bearers, spaced to suit the size of the hearth, bedded into the concrete during laying, to receive the ends of the floor boards and the margin strips.

A thin layer of cement and sand on top of the concrete forms a bed for the tiles.

Hearth with Trimmer Arch

Another method, which is considered one of the best in use, is given in Figs. 10 and 10A.

In this case a trimmer arch is built over from a splayed course, built in the chimney breast to form a skew back for the arch, to the trimmer itself. Now the arch may either be half a segmental arch as shown, where the arch goes flat up to the trimmer, or it may be a full arch, in which case a splayed piece must be fastened to the trimmer to correspond with the splayed course on the breast. A bearer must be fixed underneath between the short trimmers close to the breast to receive the laths, as before.

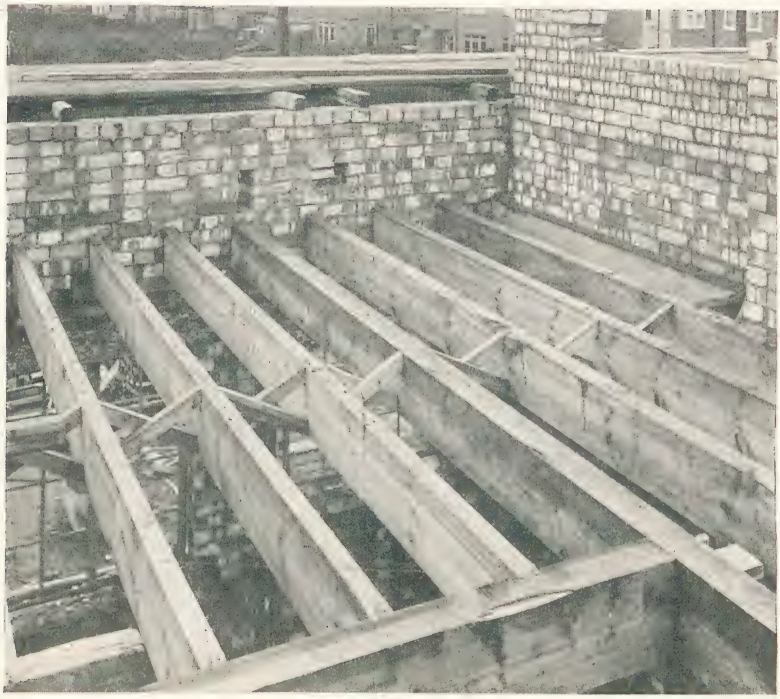


Fig. 20.—CHAMBER FLOOR JOISTS.

Here is a view of the upper floor joists showing the herringbone strutting and also the trimming. It will be noticed that a tusk tenon is used between the trimmer and the trimmer joist, whilst one of the simpler joints is used between the trimmed joists and the trimmer itself.

On the top side " firring " pieces are fitted over the back of the arch, each with its top edge level with the joists, to take the end of the boards and the margin strips. These margin strips, on a good job, will be of oak or any other hard wood about $\frac{1}{2}$ in. thick and will be rebated into the ends and edges of the floor boards and mitred round to the size of hearth required.

The back of the brick arch is brought level with concrete, cement and sand, and tiles as before.

Margin Strips

The fixing of the margin strips is best left until the tiles for the hearth are on the job, as the tiles vary in size due to burning.

On a lot of jobs the margins are of the same material as the floor boards and are put to the same depth, rebating for them being unnecessary. It is then only required to run a margin along the *ends* of the boards and mitre it into the edge of the adjoining boards.

MODERN SLATING PRACTICE

THE usual methods of preparation for slating are as follows :—

(1) Open battening or rafters.
(2) Plain boarding.
(3) Plain boarding and battens.
(4) Plain boards, felt, and battens.
(5) Plain boards, felt, counter-battens, and battens.
(6) Untearable felt and battens.

Open Battening

Open battening is more satisfactory as a preparation for slating than for plain tiling. The slates " lie closer " on the roof, and there is little penetration of draught and dirt through a slated roof.

Plain Boarding

Plain boarding is rather better than open battening, and the appearance from the inside of the roof is improved : this is important where the roof space is used. Plain boarding is hardly ever used in plain tiling, since the nibs of the tiles have to be removed (unless the tiles are nibless), and each tile has to be secured with two nails. In slating, each unit has in any case to be secured with two nails, unless the slates are 12 in. by 6 in. or smaller, when one nail per slate is used.

Other Methods of Preparation

Methods (3) to (6) are all better than (1) and (2), and one or other should be adopted where cost will permit it.

Holing and Sorting

The nail holes are usually made by the slater, but holing is undertaken by some quarries. The holes are punched on the under side of the slate, at about $1\frac{1}{2}$ in. from each edge. By this method a slight countersinking is formed on the back of the slate—the surface which is uppermost when on the roof—into which the head of the nail fits when the slates are fixed. Without this countersinking the head of the nail would remain above the surface, and the slate above would not " sit down." The position of the nail holes is shown in Fig. 1, from which it will be seen that the position of the holes depends entirely upon the gauge.

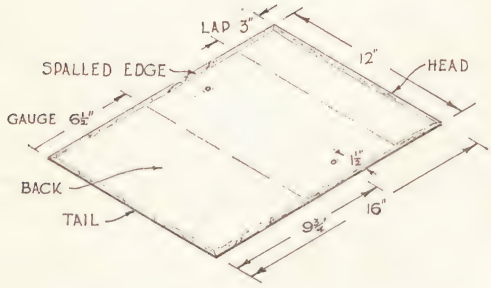


Fig. 1.—POSITION OF NAIL HOLES IN SLATE FOR CENTRE-NAILING

Centre nailing, as Fig. 1, is adopted for all except small slates or peggies, which are nailed with one nail at the head. Head-nailing is not safe where the slate is over 12 in. long, as there is risk of lifting in a high wind.

While being holed, the slates should, if necessary, be sorted for thickness. The heaviest slates should be used near the eaves, and the lightest in the top courses.

Eaves

The eaves course in slating must be formed as in plain tiling, with a double course. Fig. 2 shows the method.

Verges

Ordinary practice in slating is merely to bed and point the verge, but not to fit an undercloak. The use of an undercloak (Fig. 4) is, however, recommended as giving a better appearance from the ground, and a more secure finish. Wide slates should be used at verges and abutments in preference to cutting down an ordinary slate in width. The use of wide slates is, in fact, essential where the roofing slate is 8 in. wide or under (see Fig. 6).

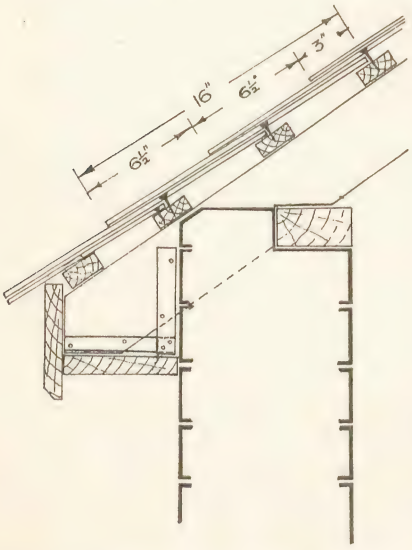


Fig. 2.—EAVES CONSTRUCTION IN SLATING

Ridges

The plain angle ridge, or some variation of it, suits a slated roof very well. The angular character of the slate seems to demand an angular finish at ridges and hips. The slates should be brought well up to the ridge tree. Half-round ridge (Fig. 3), either red or blue, may be used, and lead roll is also still popular.

Hips

Angular or other ridge tiles are, in modern practice, widely used on hips. They give excellent cover on both sides, and are not liable to removal in high winds. Lead roll may also be used.

In high-class work hips are often mitred, but unless extraordinary

Fig. 3.—MODERN SLATING PRACTICE

Showing mitred hip, bedded in coloured cement; half-round ridge; swept valley; vertical slating; slate capping to chimney. The slates are Old Delabole No. 2 grading, 14 in. long, in random widths. (*Setchell & Sons Ltd.*)

care is observed, and a good craftsman employed, the result may be unsatisfactory. The weakness of the mitred hip is that fixing can only be secured along a relatively narrow section of the slate, while the broad base of each mitred slate is exposed. The stripping of a mitred hip in a high wind is a frequent occurrence, particularly where the pitch of the roof is less than 45°, and the building is in an exposed position.

Mitred hips may be either soakered or bedded. The soakers should be of sufficient size to ensure an adequate lap at the head and side, and should be as thin as possible. Thick soakers tend to raise the hip slates, give an unsightly appearance, and assist the wind in its efforts to lift the slates. Lead soakers are here, as in all other cases, preferable to zinc. It is a

good general rule to assume that zinc is satisfactory only where it is completely exposed to the weather. Contact with mortar produces conditions favourable to the disintegration of zinc.

Bedded mitres are preferable, provided that the bedding material is not squeezed out over the face of the slate below. A batten should be fixed on the common rafters along each side of the hip tree to take the edge of the mitred slate. Ordinary glazier's putty may be used for bedding, but there is a number of suitable mastics now available, and coloured cement (Fig. 3) is also used. Too much bedding material is fatal to the appearance of the hip.

Hips may alternatively be flashed, which means, in effect, that the soakers are left exposed instead of being covered by a slate. Seating on turret or similar roofs must be "swept" round, as in Fig. 5. This is best done in small slates.

Valleys

Valleys in slating may be (*a*) mitred, (*b*) open, or (*c*) swept. The mitred valley (Fig. 5) is excellent in appearance and satisfactory in use, provided that the gutter beneath it is properly formed.

Open metal valleys are usual in all but high-class work. It is better to have a fairly wide valley, say 3 in. to 4 in., than a narrow, almost secret, gutter. Secret gutters are usually to be avoided, because of the danger of clogging with dead leaves. The wide valley ensures always a clear passage for water. Open valleys may be "left dry," or an undercloak may be fitted: the latter method is preferable. An undercloak 4½ in. wide is ample.

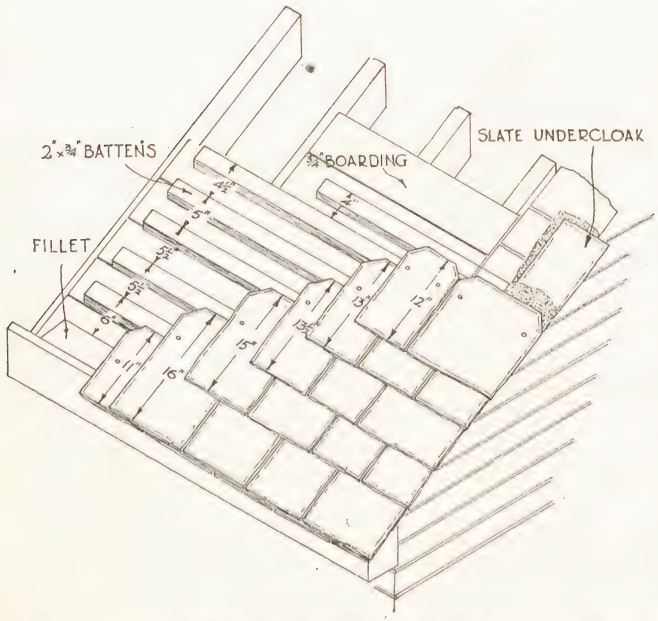


Fig. 4.—BOARDING, BATTENING, AND RANDOM SLATING; SLATE UNDERCLOAK AND WIDE SLATES IN ALTERNATE COURSES AT VERGE

Swept valleys in slating (Fig. 3)

are unusual and expensive. They can be gracefully formed only in slates of narrow width, as wide slates come round the valley in, as it were, a series of jerks, with wide spaces between the slates. With small slates a smooth curve can be formed. Large slates, again, require that the valley shall have a very wide sweep; with small slates the curve may be more restricted. The wide curve necessary with the large slate creates a difficulty at the top of the valley, and the junction with the ridge is likely to be ungainly.

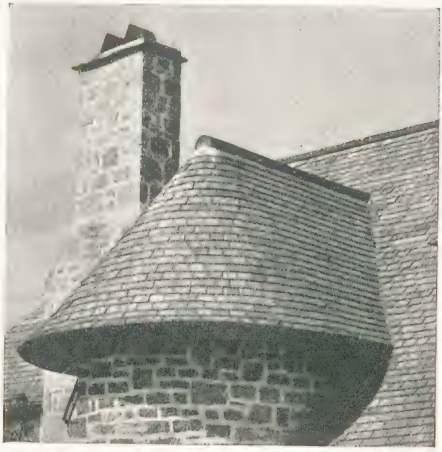


Fig. 5.—12-IN. BY 6-IN. OLD DELABOLE SLATES ON A CIRCULAR TURRET ROOF; MITRED VALLEY

Abutments

Soakers must always be used at abutments, and the width along the roof must always be sufficient to give the proper side lap. The turn-up against the wall must also be enough to ensure adequate cover by the stepped or other flashing.

Nailing

The question of nails is discussed in another place in these articles (page 211). Here we need only remind the reader that the life of a slated roof is only as long as the life of the nails. Galvanised nails should not, therefore, be used on any slated roof.

Roof Pitches

The pitch of the rafters may generally be less for a slated than for a plain-tiled roof, but the size of slate must be taken into account. Large slates may be laid on a slower pitch than small slates, and the reasons are worth remembering. There is always a certain spread of moisture on either side of the vertical joints between adjacent slates in the same course, and the slower the pitch the greater the spread. The side lap in slating is equal to half the width of the slate, and if a small slate is used on a roof of slow pitch the moisture may spread until it finds its way between the vertical joints that are covered, and so into the roof.

A further reason for using large slates only on slow-pitched roofs is that the weight to be borne by the nails is reduced to a minimum. A 24-in. by 12-in. slate may weigh up to 7 lb., and this is too great a weight to be borne by two nails on a slope of 50° or 60°.

Fig. 6.—USE OF WIDE SLATES AT VERGES OR ABUTMENTS

Random Slating

Fig. 4 is an illustration of random slating on boards and battens. Nearly all random slates are shouldered at the quarries, on account of the difficulty of ensuring trueness to width in this class of slate. The slates shown diminish from 16 in. to 12 in., and the gradual decrease in the gauge to give a 3-in. lap throughout should be noted.

The types of slate available, grading, sizes, and calculations in regard to slating are all given in Vol. III, pages 209 to 220. Calculations for battening for slates will be found on page 221 of Vol. III.

QUESTIONS AND ANSWERS

What are the usual methods of roof preparation for slating ?

(1) Open battening or rafters.
(2) Plain boarding.
(3) Plain boarding and battens.
(4) Plain boards, felt, and battens.
(5) Plain boards, felt, counter-battens, and battens.
(6) Untearable felt and battens.

Where are Nail Holes placed on Slates ?

On centre line across width of slate, except in the case of small slates or peggies, which are nailed with one nail at the head.

Why is head nailing not safe where the Slate is over 12 in. long ?

Because there is risk of lifting in a high wind.

ROOF CONSTRUCTION

PART I.—SINGLE ROOFS— LEAN-TO, COUPLE, COUPLE-CLOSE, AND COLLAR-TIE TYPES

THE roof is usually defined as the topmost external covering. Its purpose is to protect a building from the penetration of wet arising from rain and snow, and throw it clear of the walls.

Types of Roofs

There are several types of roofs, which are designated by various names according to outline or form of construction. Many considerations must be taken into account, such as the span, material used for the covering, and climatic conditions. With the increased use of steel in constructional work, roof work is no longer entirely the province of the carpenter, as it formerly was. Very large roofs are constructed of steel, with no woodwork about them. In timber roofs, those members which are subjected to tensile stresses are often of steel.

The use of timber in roof construction is now being largely confined to domestic dwellings.

Span

The *effective* span is the horizontal distance between the centres of the bearings on the supports, and the *clear* span the horizontal distance between the walls.

Pitch

The term pitch is applied to the amount of slope given to the side of a roof, and may be stated in terms of the number of degrees in the angle which the slope makes with the horizontal, or the ratio of the rise to the span, and is usually designated by a fraction. Thus, suppose the rise to be 12 ft. and the span 48 ft., then the pitch is :—

$$\frac{\text{rise}}{\text{span}} = \frac{12}{48} = \frac{1}{4}$$

The minimum pitch or inclination it is desirable to use for the various materials used for coverings is given on the following page.

PITCH OF ROOF FOR VARIOUS MATERIALS

Materials	*Pitch*	
	Minimum Angle with Horizon	*Ratio of Rise to Span*
Slates (small)	33°	$\frac{1}{3}$
,, (ordinary)	26°	$\frac{1}{4}$
,, (large)	21°	$\frac{1}{5}$
Tiles (single-lap)	35°	$\frac{7}{20}$
Plain tiles	45°	$\frac{1}{2}$
Corrugated sheets	20°	$\frac{9}{50}$
Copper and zinc	1°	$\frac{1}{80}$
Lead and asphalte	0°	$\frac{1}{120}$
Ruberoid	20°	$\frac{9}{50}$

In exposed positions these pitches should be increased over the amounts given above.

Parts of a Roof

The lowest part or edge of a sloping roof is called the *eaves*, and may or may not project beyond the wall face. Where the roof finishes over a gable end, the edge is termed the *verge*. *Valley* is the line of intersection of two roof planes containing an external angle less than 180°, and a *hip* the line of intersection of two roof surfaces which contain an angle greater than 180°. A *hipped end*, the triangular surface formed by the slope being continued round the end. These terms are illustrated in Fig. 1. *Rafters* (common) are inclined members running from ridge to eaves. Where they finish against hip or valley rafters they are termed *jack rafters*.

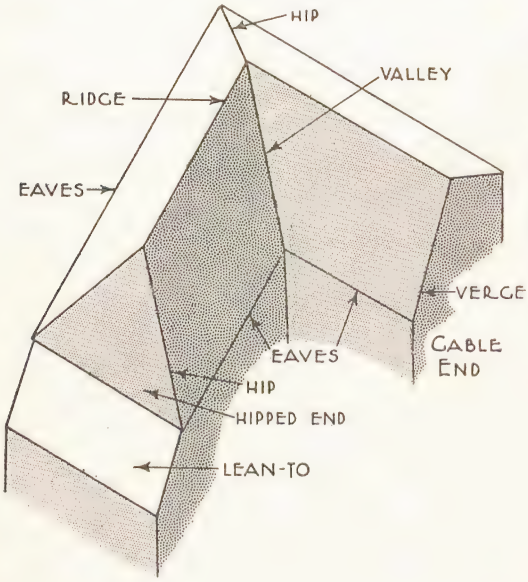
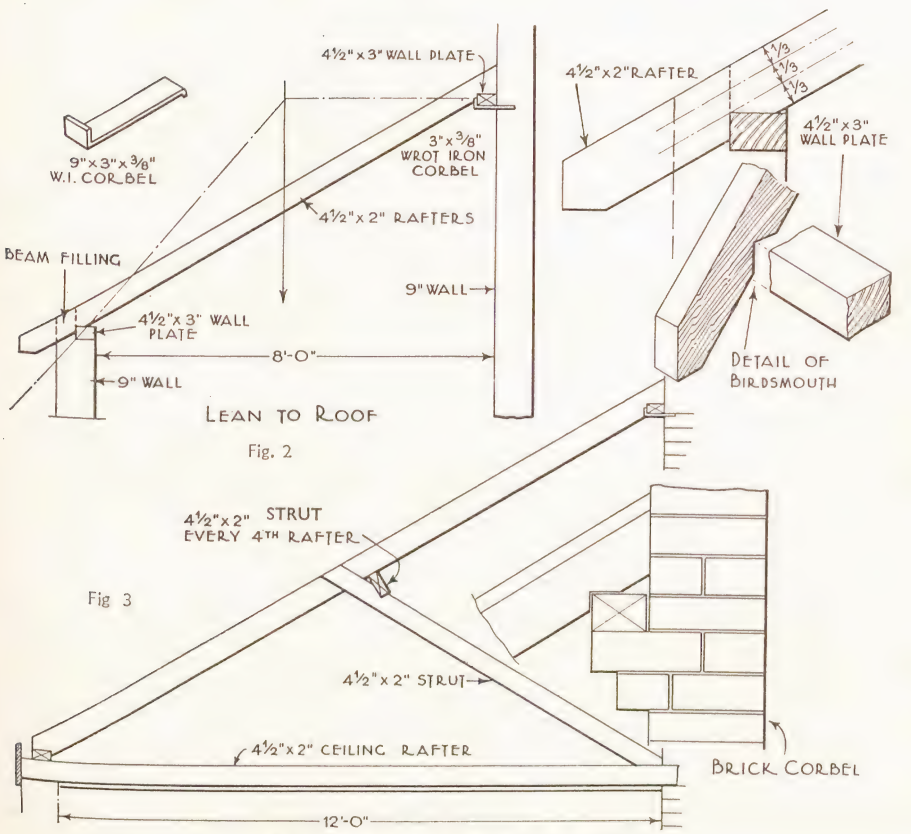


Fig. 1.—SKETCH OF ROOF, ILLUSTRATING THE TERMS EMPLOYED TO DESCRIBE PARTS

A series of rafters 12 in. to 16 in. apart is usually placed over the entire surface. If they exceed about 8 ft. in length, intermediate supports termed *purlins* must be provided for them. Generally, they run from the roof ridge or apex down to



Figs. 2 and 3.—LEAN-TO ROOFS

The span suitable for the type shown in Fig. 2 is 8 ft., but it can be increased if suitably tied and braced by the use of purlins and struts at intervals if necessary, as in Fig. 3. Fig. 3 also shows the construction of a brick corbel.

the eaves, but occasionally are placed in a horizontal position. *Wall plates*, to which the lower ends of the rafters are usually fitted with a bird's-mouth joint and nailed, should be bedded on the wall, preferably placed along the inside. For convenience of fixing the roof covering, it is necessary either to nail battens transversely at intervals or to board the rafters entirely over.

Roofs may be classified as single, trussed, composite (wood and steel), and steel.

Single Roofs

Single roofs are those which consist of a framework of common rafters alone, with a wall plate and a ridge piece, and with or without purlins. These include the following types : lean-to, couple, couple-close, collar-tie,

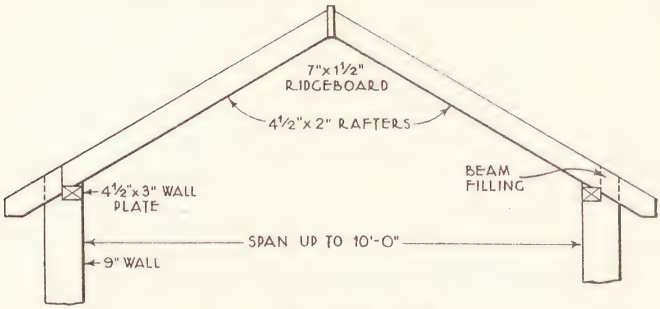


Fig. 4.—COUPLE ROOF

The weak feature of this type is that its weight does not bear vertically on the walls.

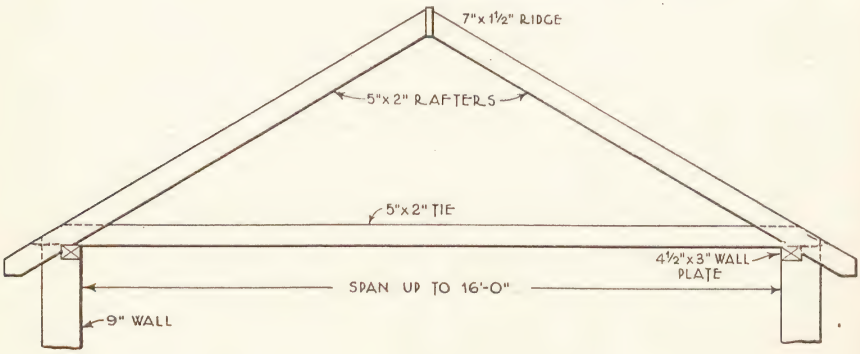


Fig. 5.—COUPLE-CLOSE ROOF

The couple-close roof is tied at the feet of the rafters. The ties act as ceiling joists where a ceiling is required.

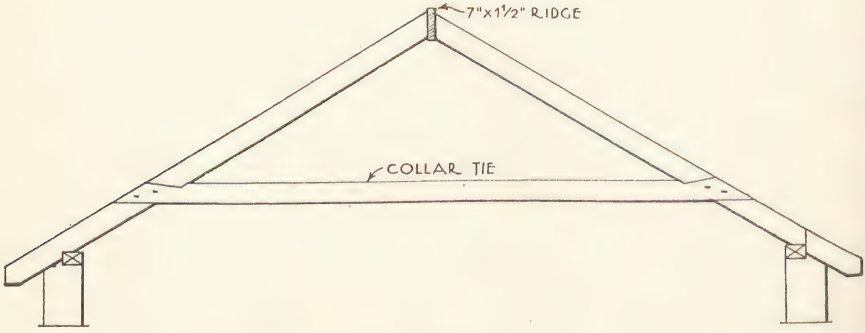


Fig. 6.—COLLAR-TIE ROOF

The tie is placed some distance above the wall plate, and is called a tie-rod if of steel and a tie-beam if of wood. It is usual to place the tie at one-third the vertical height from wall to ridge.

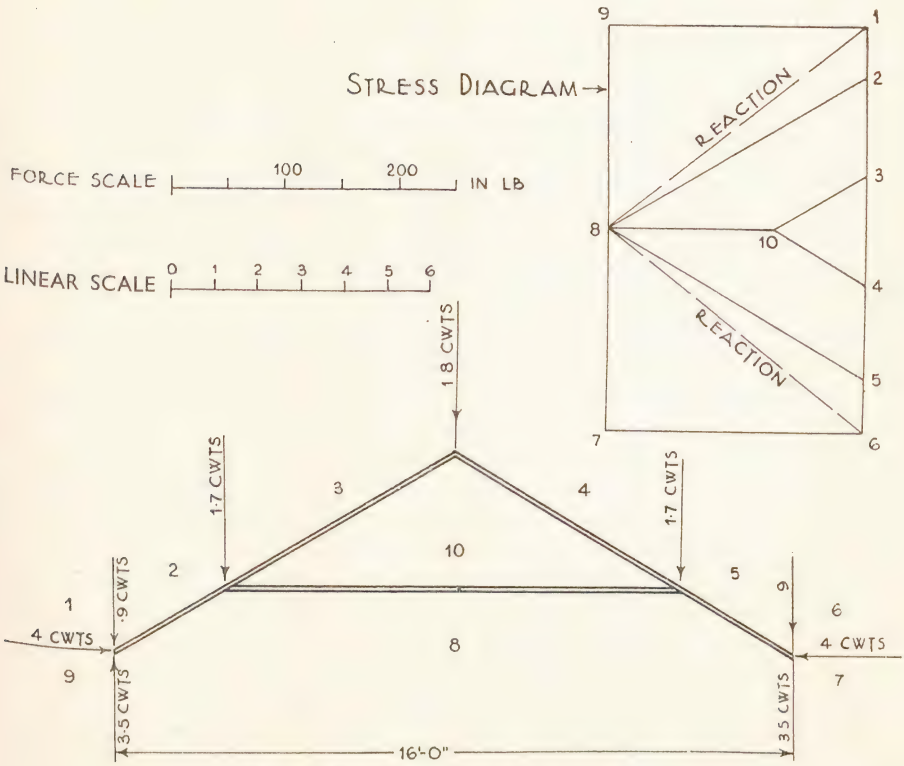


Fig. 7.—Frame diagram for rigid walls

V-roof, and flat roof. When purlins are used they are sometimes called double or purlin roofs.

Lean-to

This is formed with only one slope, and is used for sheds and buildings attached to the main buildings (see Fig. 2). The span suitable for this type is 8 ft., but it can be increased if suitably tied and braced by the use of purlins and struts at intervals if necessary (see Fig. 3). If the distance from ridge to eaves is less than 5 ft., it is not necessary to use rafters at all, but simply to board the surface over, the boards running with the slope, and a suitable support provided for them at top and bottom.

The upper ends of the rafters are fixed to a wall plate which is either built into or attached to the back wall at the desired height. When the wall plate is not built into the wall, or rests on an offset, it may be supported on a projecting course of bricks, or corbels of brick or wrought iron, at about 3-ft. intervals, built in or fixed for the purpose (see Figs. 2 and 3). The lower ends of the rafters are fitted to the wall plate in the usual way.

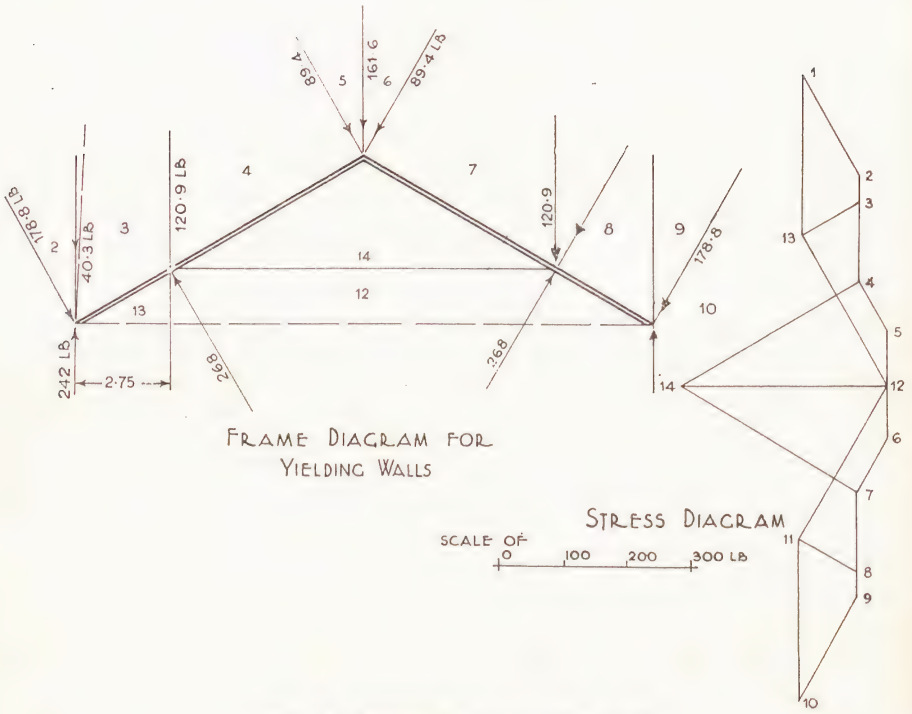


Fig. 8.—STRESSES IN COLLAR-TIE ROOF

Couple Roofs

As their name implies, couple roofs are roofs consisting of pairs of rafters fixed at their feet to a wall plate (see Fig. 4), and pitching against the ridge. The weak feature of these roofs is that their weight does not bear vertically on the walls, but tends to thrust them apart unless the walls are sufficiently strong to resist the thrust, but it is quite easy to modify its form so that all the outward thrust, or most of it, can be prevented. They are only suitable for spans up to about 10 ft.

Couple-close Roof

When the couple roof is tied at the feet of the rafters it is termed a *couple-close* roof (see Fig. 5). The weight of the roof, etc., tends to depress the ridge, and therefore the feet of the rafters will tend to spread and push the wall outwards. The tie prevents the feet from spreading, and consequently the danger of the walls overturning is avoided.

These ties also act as ceiling joists where a ceiling is required. Although the tie beam is in tension it requires to be of good depth to prevent sagging.

Where a ceiling is to be fixed a good rule is to make the depth of

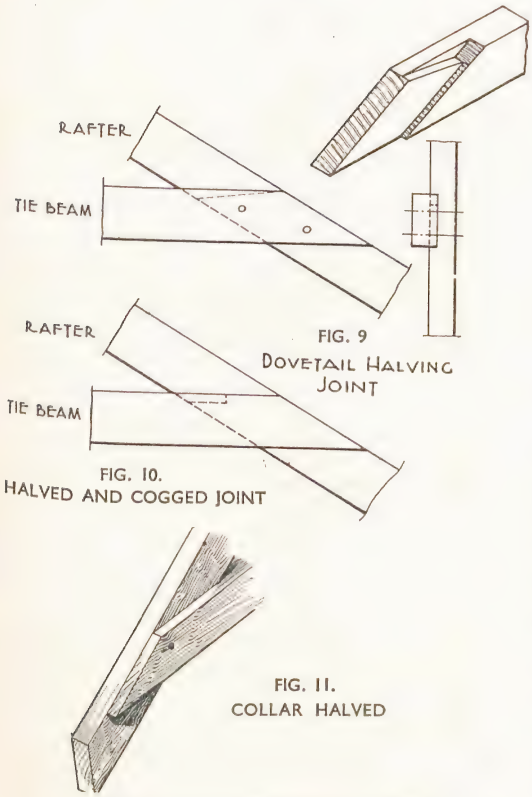


FIG. 9
DOVETAIL HALVING JOINT

FIG. 10.
HALVED AND COGGED JOINT

FIG. 11.
COLLAR HALVED

Figs. 9–11.—DETAILS OF JOINTS

the joist ½ in. for every foot of span.

Collar-tie Roof

When the tie is placed some distance above the wall plate, it is called a *collar-tie* roof (see Fig. 6). This tie is called a tie-rod if of steel, and a tie-beam if of wood. If it is placed at half the vertical height from the wall plate to the ridge, the bending in the rafter would be prevented, but in this position the tie would not be very efficient to prevent the overturning thrust on the walls. It is therefore usual to compromise, and place it at one-third the vertical height from the wall to the ridge. The collars have a dual function, according to changing circumstances. If the walls are rigid and the rafters are sufficiently stiff to stand without deflection, the collar tie will be in compression (see Fig. 7), as also will be the case under wind pressure. However, the slightest degree of settlement or the spreading of the supports and they at once become ties (see Fig. 8). In view of this alternating change in function it is well that every fourth or fifth collar should be halved to the rafters in order to form a shoulder, but it is not wise to weaken the rafter at this point by cutting into it to form the joint. These rafters should be proportionately increased in width, so as to maintain the same sectional area, as the weak point of the roof is the amount of deflection that may occur in the rafter between the ends of the collars and the wall plate.

The joint connecting the collar beam to the roof may be a dovetail-halved joint, as shown in Fig. 9, or a halved and cogged joint (Fig. 10), or the collar alone may be halved (Fig. 11).

Collar-and-tie Roof

Though the generality of textbooks deal almost entirely with roofs constructed with trusses, the greater number of small buildings are

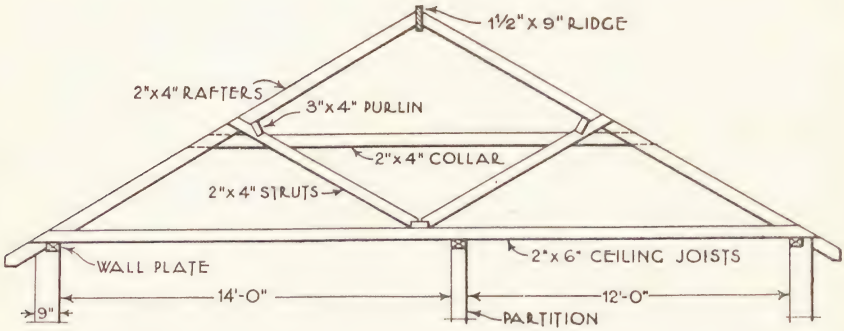


Fig. 12.—COLLAR-AND-TIE ROOF

without such provision. Besides the various forms of single roofs shown, larger spans can be satisfactorily constructed by the use of struts and ties. When constructed in this way they are known as *collar-and-tie* roofs (see Figs. 12 and 13). When this last type of roof is further strengthened by placing pairs of rafters at about 5 or 6 ft. apart, and securing with collars, struts, and hangers, they are termed *purlin* or *double-rafter* roofs. An alternative method is to carry the roof on a Howe or N girder, which forms a trussed purlin ; the top boom carries the rafters, and the lower one the ceiling rafters.

If the roof space is to be utilised as a room, then the collars will have to be raised to allow sufficient head room. The purlins can be used as ashlaring along the sides of the room and covered with a plaster board or fibre board, or the purlin filled in with studs to receive the laths for plastering.

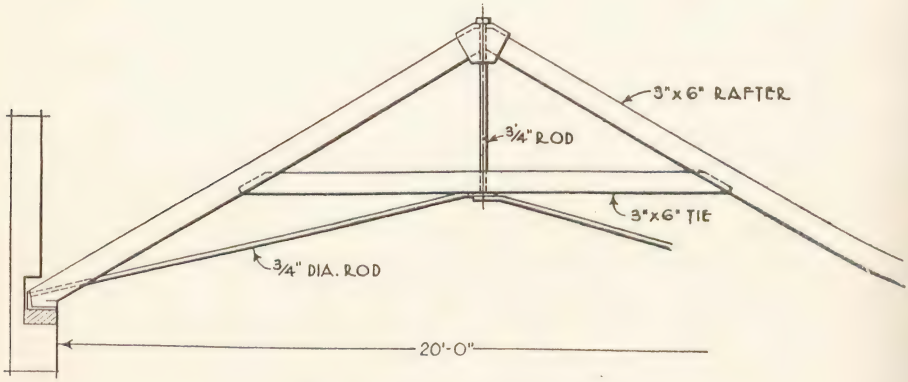


Fig. 13.—COLLAR-AND-TIE ROOF

Eaves Finish

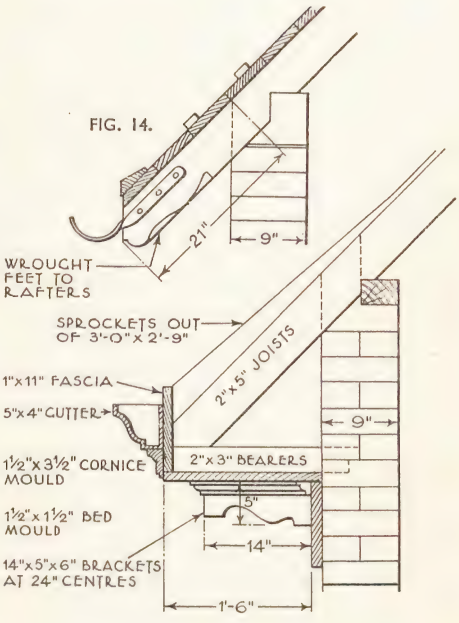
Various methods are used for finishing the eaves. In some cases they are cut off flush with the face of the wall; in others the feet of the rafters project and are wrought and in some cases moulded (see Fig. 14). They may be closed in with soffit boarding fixed to bearers, which gives a neat finish (see Fig. 15). A more elaborate method is shown in Fig. 16, where the soffit has the addition of moulded brackets or consoles.

Another and durable method is to finish the eaves with roofing tiles nailed to the fascia board in the front and resting on a projecting brick course along the wall. Tiles having a continuous nib along the top look best, and therefore make a more suitable finish than the unnibbed variety.

Tilt at the Eaves

Tiled roofs do not require any exaggerated tilt at the eaves such as is given by the use of sprocket pieces (see Fig. 16), but where such are employed care should be taken that the difference in pitch between the sprocket and the roof proper is not too great, nor that the pitch adopted for the covering at this point is too flat where a large volume of water has to be dealt with.

Sprockets may be fixed to the top of the rafters or nailed to their sides.



Figs. 14–16.—EAVES DETAILS

Fig. 14.—Feet of rafters projecting and wrought. *Fig.* 15.—Feet of rafters projecting and closed in with soffit boarding. *Fig.* 16.—Soffit with moulded brackets.

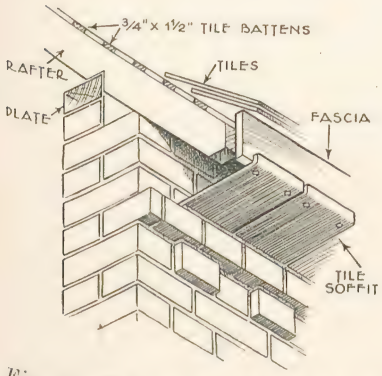


Fig. 17.—EAVES FORMED WITH FASCIA BOARD AND TILE SOFFIT

Fig. 18.—FEET OF RAFTERS SHOWING BIRD'S-MOUTH JOINT ON THE WALL PLATE

QUESTIONS AND ANSWERS

What is meant by the "effective span" and the "clean span" of a roof?

The effective span is the horizontal distance between the bearings on the supports, and the clear span is the horizontal distance between the walls.

To what is the term "pitch" applied?

To the amount of slope given to the side of a roof.

How is the pitch of a roof described?

It may be stated in terms of the number of degrees in the angle which the slope makes with the horizontal, or the ratio of the rise to the span, and is usually designated by a fraction.

How far apart are rafters placed from each other?

12 in. to 16 in.

When are purlins employed?

When the rafters exceed about 8 ft. in length.

What are single roofs?

Those which consist of a framework of common rafters alone, with a wall plate and a ridge piece, and with or without purlins.

WOOD FLOOR CONSTRUCTION

PART II.—DOUBLE FLOORS

SO far we have dealt in detail only with single-joist floors (see pages 241–256), and it was then suggested that that form of construction would be suitable for floors with a span up to 16 or 18 ft.

It is quite conceivable, however, that we could have a floor of 16-ft. span which would be expected to support unusually heavy loads, and when the section of joist was calculated for a single system of members it would be found to be excessively large, and it would prove more economical to use what is termed a " double floor."

A double floor is illustrated in Fig. 1, where it will be seen that extra members, referred to as " binders," have been introduced.

This form of floor construction is necessary, in certain cases, for floors of 16-ft. span, as already explained, and it is also suitable for floors of 24-ft. span which are not expected to carry heavy loads ; whilst in exceptional cases of very light loads it is possible to exceed 24 ft.

Thus it will be seen that the type of floor is dependent quite as much on the form of loading as upon its span, and on calculating for the section of the joists to suit the particular conditions it may be found that by using another type of floor the nett cube timber required will be reduced.

Binders

Wood, with few exceptions, was until recent years the only material used for binders in double floors, but nowadays we are living in the steel age, and the use of wood is fast becoming the exception.

Advantages of Steel

The main advantages to be gained by using rolled-steel joists in place of wood are : reliability as regards strength, a wide range of sections and lengths, and a reduction in the size of section required.

There are many occasions, however, when the choice of material for a binder is not decided by these factors alone, as for example :—

Use of Timber Binders

In certain manufacturing industries and some printing processes, chemicals are used which would very soon cause great damage to the rolled-steel joists by their corrosive action.

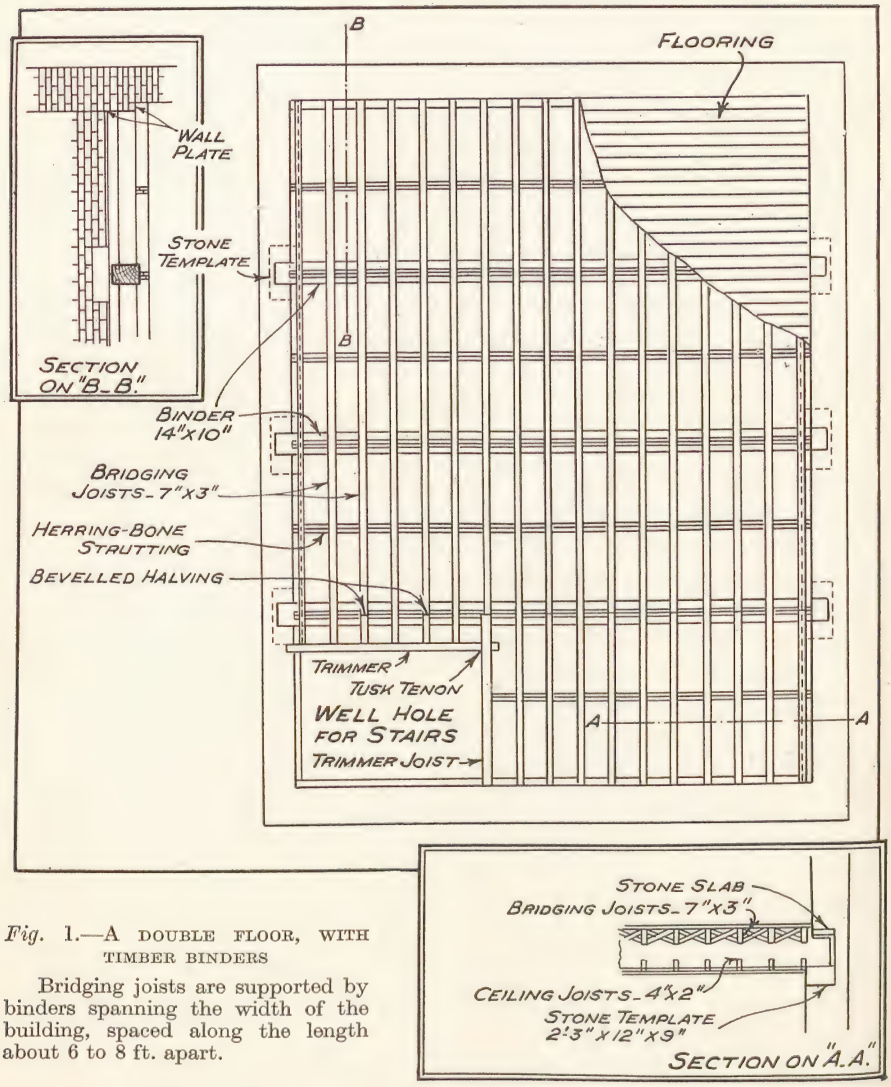


Fig. 1.—A DOUBLE FLOOR, WITH TIMBER BINDERS

Bridging joists are supported by binders spanning the width of the building, spaced along the length about 6 to 8 ft. apart.

Encasing the R.S.J.s with timber would help to prolong their life, but it is not possible entirely to safeguard against these chemical fumes, and the only expedient is to use a timber binder.

In other manufacturing processes the structure of the building is subject to very rapid and unequal changes of temperature, and steel, with its comparatively great coefficient of expansion, would very soon bring about the collapse of the whole building; here, again, timber is the only alternative.

Fire Resisting

Another very big point in favour of timber is its ability to resist destruction by fire.

This may sound ridiculous, but when one remembers the twisted and buckled girders to be seen amongst the wreckage of a building destroyed by fire, it is the idea that steel is a security against fire which becomes ridiculous. Timber, on the other hand, once it has become charred, will require considerable further heat, from an outside source, before it can be burnt through, and its expansion and twisting can be considered negligible.

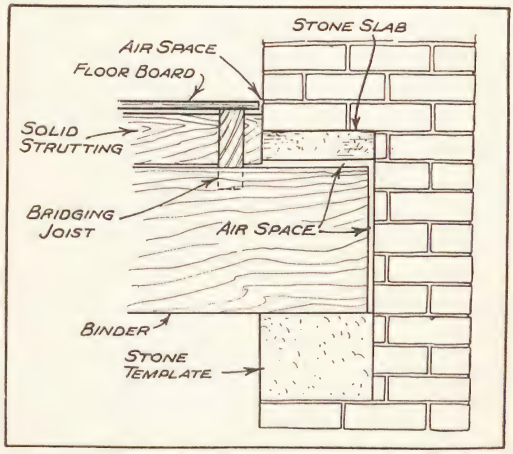


Fig. 2.—STONE TEMPLATE SUPPORT FOR BINDER

Thus, it will be seen that, whilst steel is to be preferred in some cases, it cannot entirely replace timber in every case.

On reference to Fig. 1, it will be seen that the bridging joists are supported by binders spanning the width of the building. That they should run the shortest way of the building is important, and they should be spaced out along the length about 6 ft. to 8 ft. apart. The spacing of the binders is affected by the position of the door openings and windows of the room below, or by the location of the pieces along the length of the building.

Now, for the double floor shown in Fig. 1, timber binders are used, but the arrangement would have been very similar if rolled-steel joists had been employed. We will therefore outline the main features of a double floor as shown in Fig. 1, and then go on to explain the different treatments of the two kinds of binders.

Support of Binders

The binders are supported in the walls in a similar way to the floor joists for a single floor, except that a little more attention has been paid to the method of supporting them. Here, stone templates are used, about 18 in. by 12 in. by 9 in. deep, built into the brickwork as shown in Fig. 2, to distribute the load.

Air space is provided round the ends and on the top of the binder, the latter being made possible by using a further stone slab bridging the brickwork on each side of the binder.

The ceiling joists are supported on a built-in wall plate, and a further wall plate is embodied to support the bridging joists.

A staircase well is also indicated in Fig. 1, and the bridging joists at

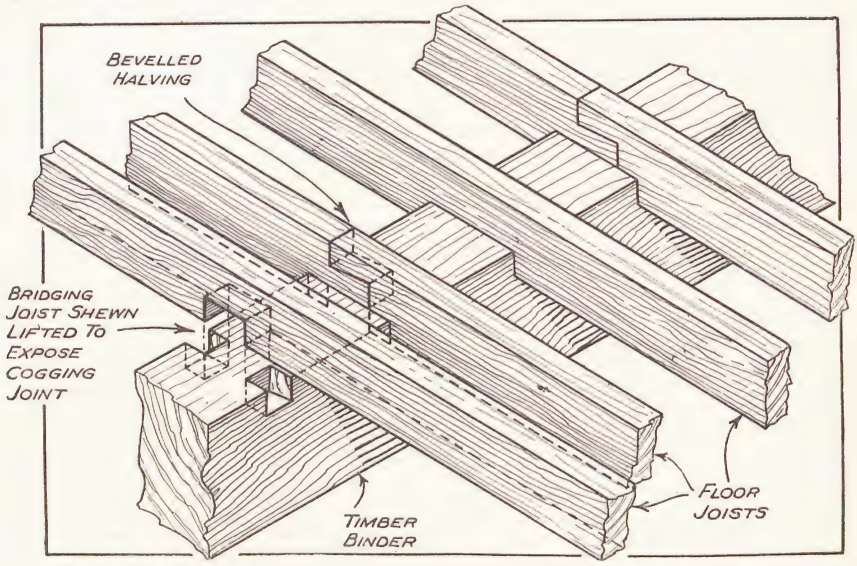


Fig. 3.—METHOD OF SUPPORTING BRIDGING JOISTS ON A TIMBER BINDING

Showing construction of cogging joint between joist and binder and bevelled halving joint between two joists.

this point are trimmed after the manner described in the previous section on floor construction, page 250.

We will now consider the method of supporting the bridging joists on both types of binders, and the treatment of the steel binders.

It should be noticed in Fig. 1 that the bridging joists are long enough to span two bays, and the joints between the joists occur alternately on each binder, thus tying the binders one to the other ; further illustrations of this are given in Figs. 3 and 13.

Cogging Joint and Bevelled Halving

A local view of the bridging joists supported on a timber binder is given in Fig. 3. Here the construction of the *cogging joint* is clearly shown, where the first joist has been lifted out of position. The joint between the ends of two joists is called a *bevelled halving* and, as will be seen from the figure referred to, it is so designed that when the floor-boards are laid, the weight put on the floor will tend to hold the ends of the joists together. All the joists are cogged on to the binder, whether they are jointed on the top of it or not.

Strutting

As a precaution against the joists rocking on the binders, which is liable to happen when a large portion of the joist is above the binder, strutting is introduced between the joists. This may take the form of

solid struts as shown in Fig. 13, or herringbone strutting as illustrated in Figs. 10 and 14; comparisons of these two types of strutting have been given in the earlier section on floor construction. It is necessary, when cogging the joists, to make sure that their top edges are level, and any joists which are not straight must be laid with the round edge to the top.

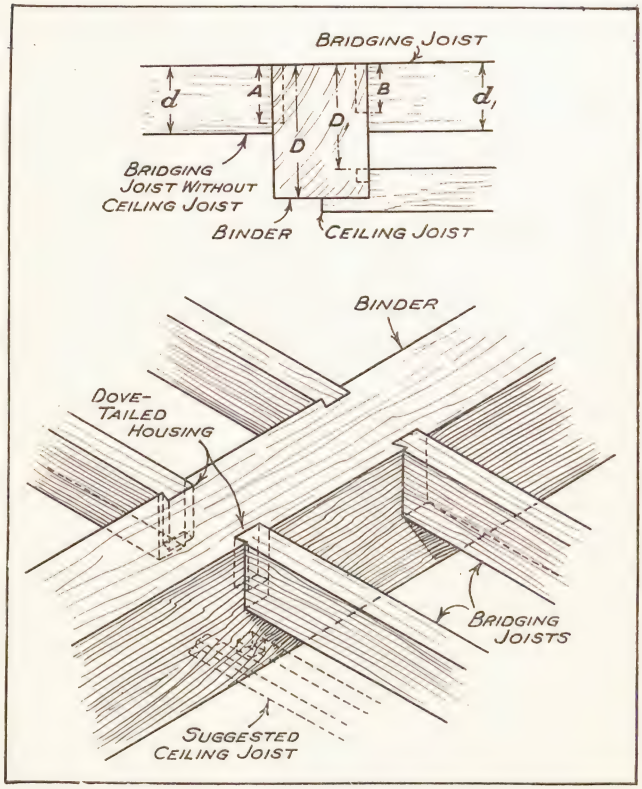


Fig. 4.—METHOD OF FRAMING JOISTS BETWEEN BINDERS

This is necessary in cases where the depth of the floor is required to be as shallow as possible.

Joists Framed between Binders

A further case, in connection with timber binders, is when the depth of the floor is required to be as shallow as possible, and this necessitates the bridging joists being framed between the binders. Now the treatment for this framing can be similar to the treatment for hearths and manholes, etc., introducing the bevelled or the square housing, or better still the tusk tenon without the peg; but with any of these there is no lateral strength, i.e. nothing to hold the joist in the binder except the nails, which cannot be relied upon. A better method is to use the dovetailed housing as illustrated in Fig. 4. Here, in this case, a portion of the bridging joist is dovetailed into the side of the binder, bringing the top edges flush. The part of the joist which is dovetailed may be anything from half to three-quarters of the depth of the joist, providing this does not result in the housing being more than half the depth of the binder. If ceiling joists are also framed in this floor, as described later, then the depth of the housing should not be greater than half the depth between the top side of the mortice for the ceiling joist, and the top of the binder.

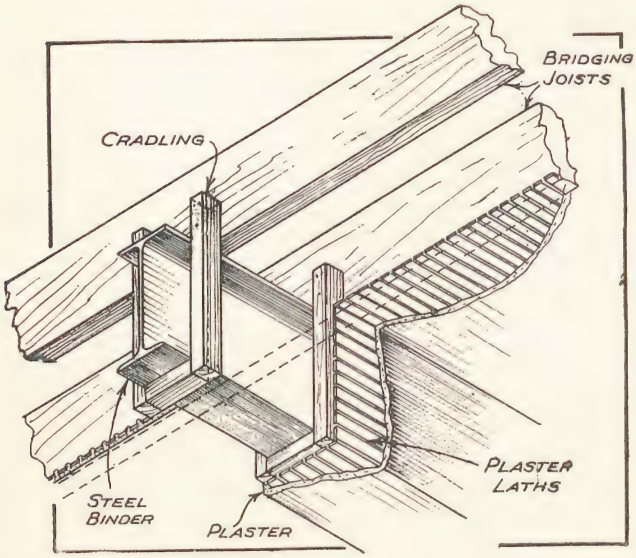


Fig. 5.—TREATMENT OF STEEL BINDER SUITABLE FOR LATH AND PLASTER CEILING WHERE BRIDGING JOISTS RUN ACROSS TOP FLANGE OF THE BINDER.

If excessive cutting is necessary when framing the bridging joist, an allowance has to be made when calculating for the sizes of the members.

Steel Binders

We now come to consider the treatment for steel binders, and have quite a number of methods from which to choose.

It will be realised that the effective depth of the floor will affect the adoption of any particular method to a very great extent.

We will first consider Figs. 5 and 6, where the bridging joists run straight across the top flange of the binder, and where the only notching necessary is to ensure the top edges being kept level.

The conditions here are very similar to the case of the timber binder, the bevelled halving being used on alternate joists.

As we are first of all considering the case where no ceiling joists are to be used, we will here explain the treatment of the steel binders to receive the ceiling preparation.

Cradling

It is necessary to affix what is termed *cradling*, around the rolled-steel joist, and in Fig. 5 the simplest method is shown. Here the firring pieces are only fitted around the outside edges of the binder and are nailed to the sides of the bridging joist, one to each joist, along the length of the binder. This arrangement is suitable only for lath and plaster ceilings as shown. When we have to support heavier forms of ceilings, it is necessary to adopt the method shown in Fig. 6.

In this case, the cradling is fitted tightly around the flanges of the binder, as well as being nailed to the joists above.

The deeper this cradling is let on to the steel joist, the stronger the job becomes, and the best result is obtained when the firring is fitted in up to the web of the binder. The increase in depth of the firring, neces-

sary for the cradling to fit up to the web, may seem excessive, but there is a lot to be gained, for there is less risk of the cradling becoming loose when shrinkage occurs.

In Fig. 6 the binder is encased with panelling, and a small cornice is used in the angle between the binder and the ceiling.

When it is not desirable for the full depth of the rolled-steel binder to project into the room below, the bridging joists are notched round the top flange of the binder.

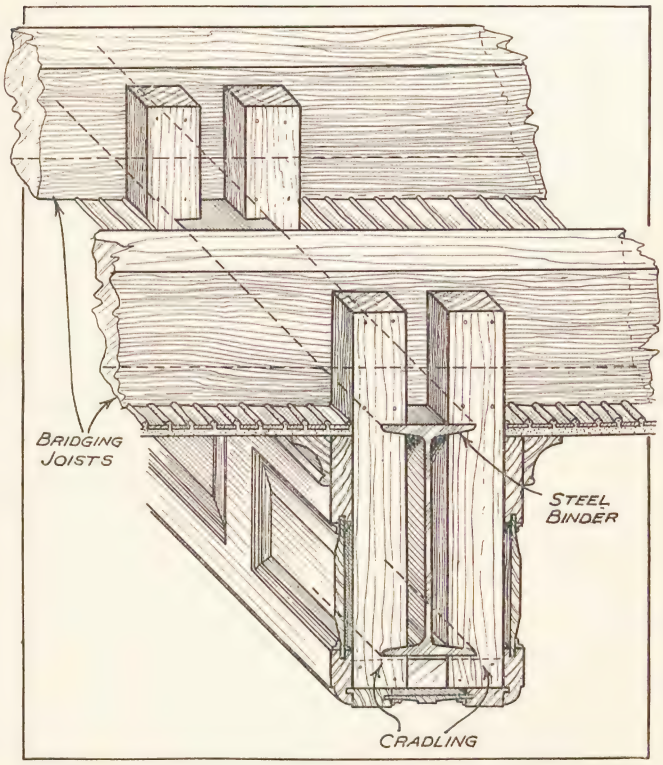


Fig. 6.—STEEL BINDER ENCASED WITH PANELLING WHERE BRIDGING JOISTS RUN ACROSS TOP FLANGE OF BINDER

The construction varies according to how much of the binder is to be allowed below the bottom edge of the joists, and upon the relative proportions of the joists and the binder.

Bearing-point of Joist

If more than half of the depth of the joist remains on top of the binder, as shown in Fig. 10, then the joist can bear on the top flange.

When, however, the portion above the binder is less than half the depth of the joist, then the joists are supported on firring pieces, bolted to the web of the binder, as shown in Fig. 7. These firring pieces are fitted down on to the bottom flange of the binders, and the whole of the weight supported by the bridging joists is taken by them.

Shrinkage Allowance

On examination of Figs. 7 and 9, a clearance will be noticed between the top of the flange and the bridging joist, and the bearing of the joist is taken by the firring in the first case, and the bottom flange of the

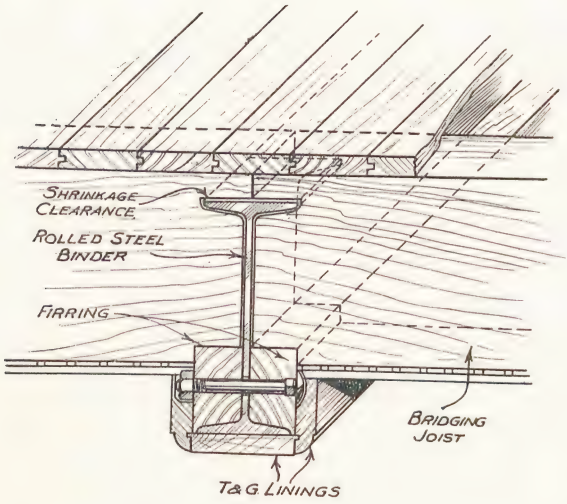


Fig. 7.—CONSTRUCTION WHERE PORTION OF BRIDGING JOIST ABOVE THE BINDER IS LESS THAN HALF THE DEPTH OF THE JOIST

usual alternative to plaster, for small binder in the second case.

This clearance is very important, for it ensures that, after shrinkage of the joists and the firring, none of the load will be brought on to the small portion of joist above the top flange. If this allowance were not made, the weight of the floor would split the joists, and a very uneven floor would result.

A further feature, in Fig. 7, is the casing in of the lower portion of the binder, which is carried out by linings tongued and grooved together, with an ovolo mould on the corners. This is the projections.

Binder within Depth of the Floor

The next method to be considered is when the whole depth of the binder must be kept within the floor, which means that the binder cannot project into the room below.

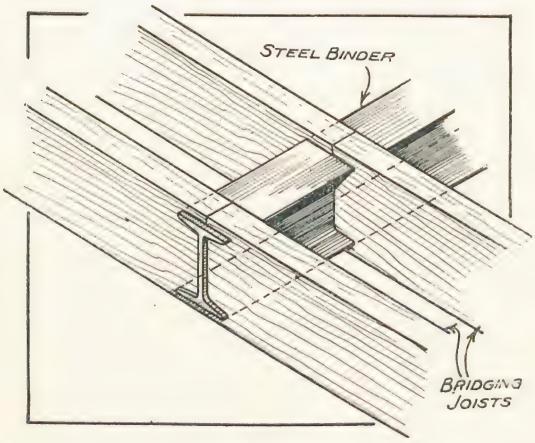


Fig. 8.—CONSTRUCTION WHERE BINDER IS HEAVY-SECTION STEEL JOIST WITH WEB 10 IN. DEEP

Note the bridging joists are fitted around the flanges of the binder. A more detailed view is shown in the next illustration.

This can be arranged in two ways: either by the use of separate ceiling joists, or by having the bridging joists deeper than the rolled-steel binder, and keeping the binder within the depth of the joists.

Without Ceiling Joists

Treating the latter case first, this method is very suitable when the depth occupied by the floor is a consideration, for when ceiling joists are used, the

effective depth of the floor is greatly increased.

Rolled-steel joists are made in a great variety of sections, and it is possible to obtain a heavy-section joist, which has thicker flanges, and web 10 in. deep, which will support a greater load than a light-section joist 14 in. deep.

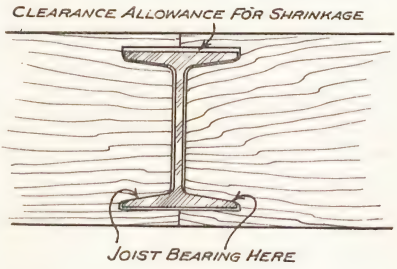


Fig. 9.—A DETAILED VIEW OF JOINT BETWEEN BRIDGING JOISTS AND HEAVY-SECTION ROLLED-STEEL BINDER

In Fig. 8 a heavy-section rolled-steel joist is used for the binder, thus bringing it within the depth of the joists. The joists are fitted around the flanges of the binder, with a small portion running over and under the top and bottom flanges, in order to receive the floor and ceiling coverings respectively.

A more detailed illustration of this is given in Fig. 9, which shows more clearly where the weight of the joist is supported, and also indicates the shrinkage allowance on the top flange of the binder, which was explained earlier.

Ceiling Joists with Steel Binders

Where ceiling joists are used, as previously referred to, they are fitted round the bottom flange of the binder, with the bridging joists fitted round the top flange, as in previous cases. This will be clear from Fig. 10.

When a particularly deep-section rolled-steel joist is necessary for the binder, and the bridging joists have to be lowered, to reduce the depth of the floor, it may result in the top flange coming into the top half of the bridging joists, and then the latter must be supported at their bottom edge.

A good way of doing this is to bolt angle iron on to each side of the web, along the length of the binder, to support the bottom edge of the bridging joists, and in Fig. 10 the position of

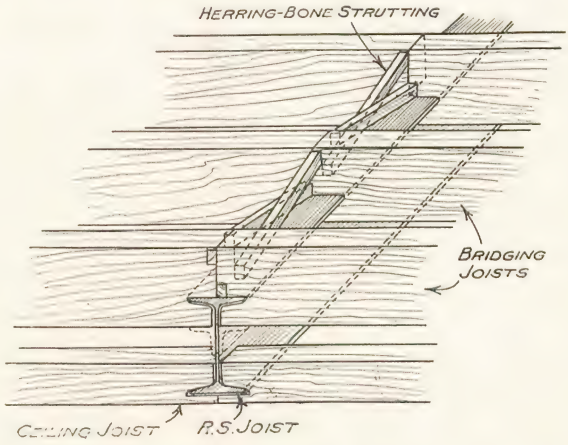


Fig. 10.—CONSTRUCTION WHERE CEILING JOISTS ARE USED

Angle iron bolted to web, which would be required if the top flange comes into the top half of the bridging joist, is shown dotted.

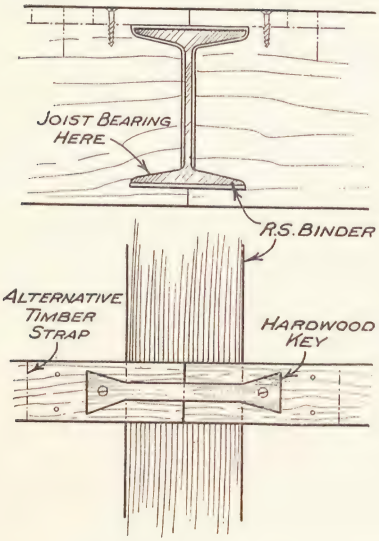


Fig. 11.—METHOD OF STRAPPING ENDS OF JOISTS

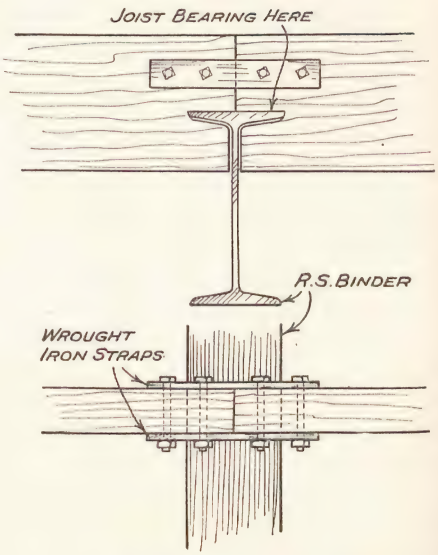


Fig. 12.—ANOTHER METHOD OF STRAPPING ENDS OF JOISTS

this angle iron is shown dotted, for it would not be necessary in this particular example.

Where separate joists are used for floor and ceiling, with a cavity between them, a sound-resisting effect results.

It is essential that a portion of the ceiling or bridging joist should pass under the bottom of the binder in Figs. 8 to 11, as otherwise, if the plaster laths were in contact with the lower edge, there would be no room for plaster to key behind the laths. For steel binders, special expanded metal lathing can be used, which overcomes this difficulty, with a further advantage in the reduction in the depth of the floor.

Strapping Ends of Joists

In cases where the joists are notched round the binder, as in Figs. 7, 8, 9, and 10, it is impossible for them to span more than two binders, so that the task of tying them together becomes more difficult. Even if there is more than half of the bridging joist above the top flange, it will not be possible to use the bevelled halving joint, unless the joists are supported at their bottom edge, or the flange of the binder is exceptionally wide, which would allow for a bearing at each side of the halving.

Floorboards Not Sufficient

It might be considered sufficient to depend upon the floorboards holding them together, but this is assuming a floorboard will always be

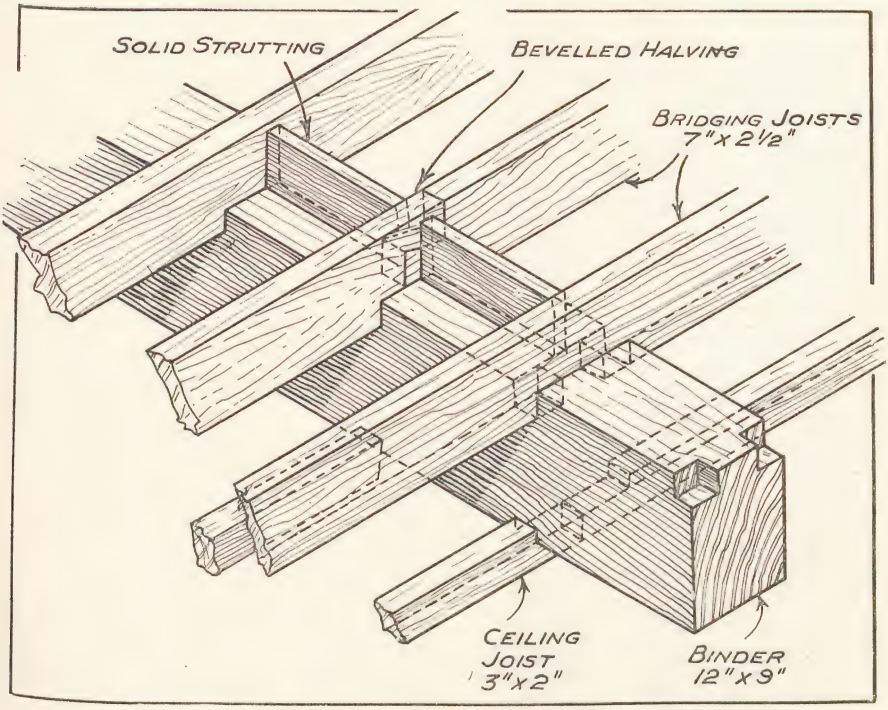


Fig. 13.—SMALL-SECTION CEILING JOIST FOR TIMBER BINDER

central over the two ends of the joists, which is not to be relied upon.

When a reasonable proportion of the joists is above the binder, they can be nailed together or secured by steel dogs ; a better method is to splice the ends together by cutting away the top edge of the joists about 1 in. to 1½ in. deep for a few inches either side of the binder, and letting in a piece of timber, which is nailed in position after the joists have been fitted, to strap the ends together, as shown in Fig. 11.

Another very effective method of dealing with the above case is to strap the ends of the joists together with wrought-iron plates (see Fig. 12) ; this need occur only on occasional joists, the remainder then being simply nailed.

A good method suitable for cases where only 1 in. or so of the joist is above the top flange is illustrated in Fig. 11, where a hardwood key is dovetailed into the top edges of the joists when the joists are in position.

Ceiling Joists for Timber Binders

So far we have only dealt with ceiling joists in connection with steel binders ; we will now consider their treatment when fitted to timber binders.

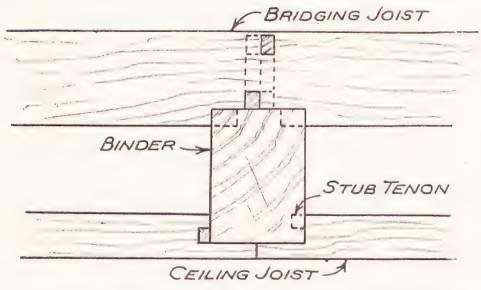


Fig. 14A.—TWO METHODS OF SUPPORTING CEILING JOISTS

Where the ceiling joists are only of small section, it is sufficient for them to be notched round the bottom edge of the binder and secured by nails as in Fig. 13, but when they are of heavier section it is advisable to provide a more reliable support.

The method shown on the right-hand side of the binder in Fig. 14A makes a first-class job : here the ceiling joist is tenoned into the binder; the method shown on the left-hand side in the same figure is a cheaper method but not so satisfactory, as the weight of the ceiling is then supported only on nails.

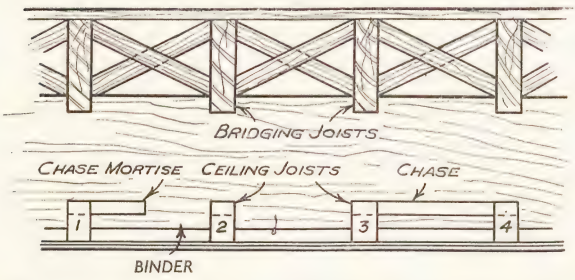


Fig. 14B.—TWO WAYS OF GETTING CEILING JOISTS INTO POSITION AFTER BINDERS HAVE BEEN BUILT IN

With the first method, there is the difficulty of getting the joists into position after the binders have been built in, and this is overcome in either of the two ways illustrated in Fig. 14B.

Chase Mortice Used

No. 1 joist is fitted into a *chase mortice* which runs out on to the face of the binder ; this allows the joist to slide into position after the opposite end has been fitted into the other binder in a mortice similar to the one shown at No. 2.

In between the joists Nos. 3 and 4 the chase is carried from one mortice to the next, so that the joists can be easily slipped into position and the chase afterwards filled in.

Further Notes on Cradling for Rolled-steel Joists

Cradles to which wood lathing or expanded metal is to be fixed for plastering should be of no greater distance apart than ordinary floor or ceiling joists, and consequently a good limit is 14-in., or preferably 12-in., centres. Those to which wood linings, casings, or similar work are to be fixed may be at centres apart equal to about 12 in. for every $\frac{1}{2}$-in. thickness of the linings to girders or blockings at 2-ft. centres.

Sizes of Members

As the loads that are supported by cradles are usually quite light, the sizes of the members of them may be small, subject to certain practical considerations.

The width of the timbers to which laths, expanded metal, linings, etc., are fixed, should be wide enough to prevent screws or nails splitting the wood, and for this reason the width should be not less than $1\frac{1}{4}$ in., and preferably greater, say $1\frac{1}{2}$ in. or 2 in., the latter size being useful where bolts have to go through.

Fig. 15.—EXPANDED METAL CASING AROUND R.S.J.

The depth of the members may be small, and anything from $1\frac{1}{2}$ in. up to 3 in. A good rule is to make the depth not more than 2 in. for an unsupported length up to 18 in., and then to add $\frac{1}{2}$ in. for every 6-in. increase in length. By this rule a member in a cradle that is 2 ft. long would be $2\frac{1}{2}$ in. deep, and would probably be of 3-in.-wide stock-size timber.

Simple Type of Cradling

Fig. 16 shows one of the simplest types of cradling, or what is in this case more commonly termed "firring," by means of blocks of wood wedged tightly between the flanges of rolled-steel joists or steel channels, or by such blocks bolted to the steelwork. The blocks of wood must have their grain, or fibres, at right angles, or end grain, to the surface of the steel against which they are wedged. According to theory most timbers do not contract or expand or warp in the direction of the length of their fibres, but only in the direction across the fibres. Provided that the blocks are end-grained as explained, and are cut truly to the slope of the steel flanges and driven tightly home, they form a reasonably good job. There is, however, no question that bolting in addition is to be preferred. When it is considered that a hole through steelwork costs about 3*d*. when

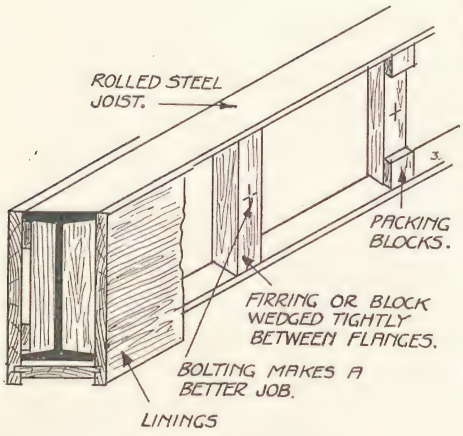


Fig. 16.—A SIMPLE TYPE OF CRADLING OR FIRRING BY MEANS OF BLOCKS OF WOOD

drilled at the structural engineer's works, and that a ½-in. bolt costs but a few pence, and that often but a few are required, it behoves all that are interested in good-quality building to insist that bolts be used.

Where the Structure Forms the Cradle

Fig 17 depicts a common instance where the timber plate and packing blocks form, in themselves, the cradling or firring quite suitable for the fixing of linings or plaster work. If the packing blocks put in for structural purposes are too far apart to provide adequate fixing for the linings, etc., then it is a simple matter to fix a few more. As packings are usually driven well home, it will often be found that their faces are not quite in the proper plane to allow for work to be directly applied to them, in which case a little additional packing on the faces may be necessary. If care is taken in shaping the blocks they may be fitted so as to provide a proper fixing for the applied work.

Counter-lathing

Where plaster has to be applied to any broad surfaces, such as timber plates or the flanges of steelwork, to which it will not adhere without the aid of lathing, it is customary to wrap the work with expanded metal or wood lathing. The former is extensively used ; and it is advisable to use stout-gauge material. It is advisable not to apply wood laths direct to wood plates, nor to wrap expanded metal around or fixed in close contact with metal or wood, but to counter-lath or firr-out the surfaces. Fig. 19 indicates an example of how the work should be done.

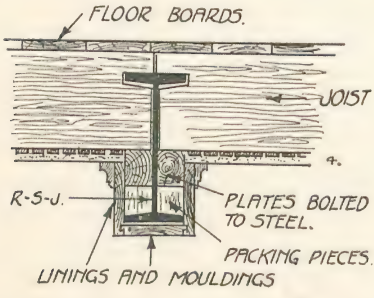


Fig. 17.—A VERY SECURE FIXING FOR LININGS

Cradling a Beam

Fig. 18 shows what may be termed a proper cradle, when considered in relation to the previously described simple types, which are really firring-out. It will be seen that the cradle is formed of distinct and properly spaced members suitable for the applied work.

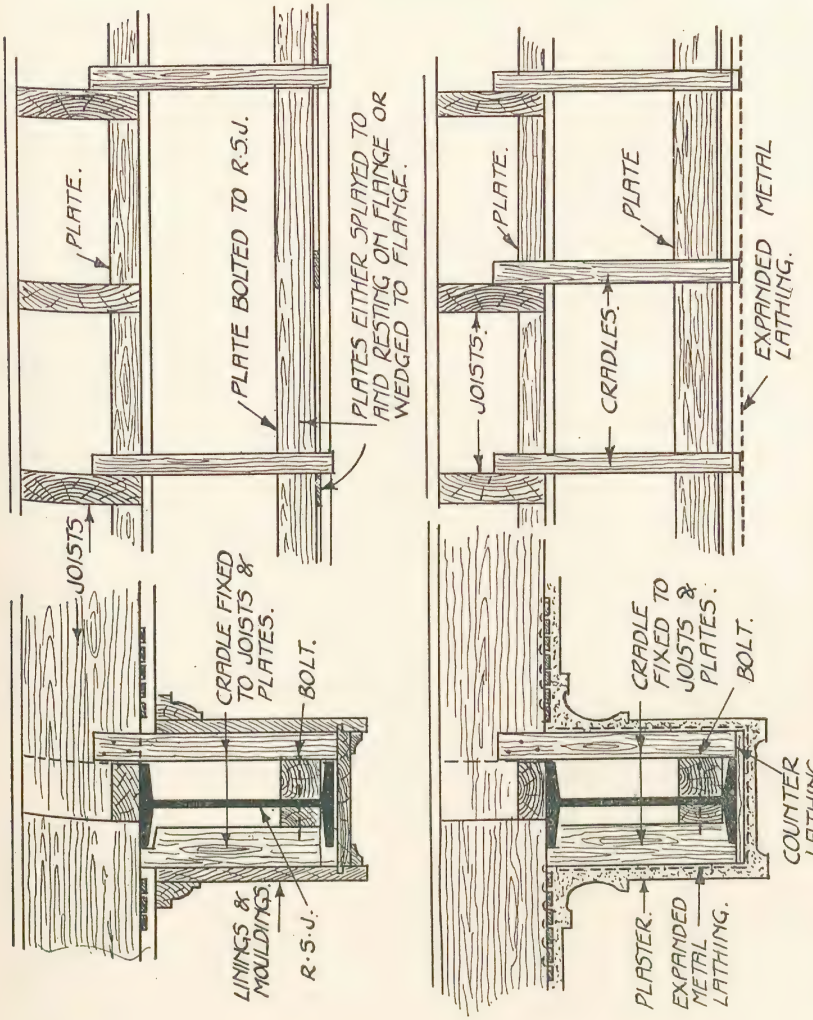


Fig. 18.—GOOD METHODS OF CRADLING ROLLED-STEEL JOISTS FOR ENCASING WITH TIMBER LININGS OR PLASTER

QUESTIONS AND ANSWERS

How are Bridging Joists supported on timber binders?

The joists should be long enough to span two bays. The joints between the joists should occur alternately on each binder. All the bridging joists should be secured to the timber binders by means of cogging joints, whether they are jointed on the top of them or not. The joint between the ends of two joists should be a bevelled halving.

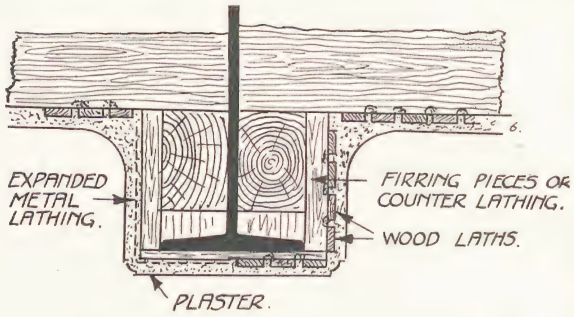


Fig. 19.—EXAMPLE OF COUNTER-LATHING

For what purpose is the Bevelled Halving Joint between the ends of two joists designed ?

It is designed so that when the floorboards are laid, the weight put on the floor will tend to hold the ends of the joists together.

What precaution is taken to prevent the Bridging Joists Rocking on binders ?

The introduction of strutting between the joists.

What precaution is necessary when Cogging the Joists ?

To make sure that their top edges are level. Any joists that are not straight must be laid with the round edge to the top.

What arrangement is employed when the Depth of the Floor is required to be as Shallow as possible when timber binders are used ?

The bridging joists are framed between the binders.

What precaution should be employed when using the Dovetailed Housing Method of framing Bridging Joists between timber binders ?

With this method a portion of the bridging joist is dovetailed into the side of the binder, bringing the top edges flush. The part of the joist which is dovetailed may be anything from half to three-quarters of the depth of the joist, providing this does not result in the housing being more than half the depth of the binder. If ceiling joists are also framed in this floor, then the depth of the housing should not be greater than half the depth between the top side of the mortice for the ceiling joists and the top of the binder. If excessive cutting is necessary when framing the bridging joist, an allowance has to be made when calculating for the sizes of the members.

COPPER ROOFING PRACTICE

By courtesy of Fred. Braby & Co. Ltd.

Fig. 1.—FLAT COPPER ROOF LAID WITH WOOD ROLLS

Notice also the copper dormer cheeks fixed without dots, which would be necessary in lead to prevent "creeping."

UNTIL a few years ago, the copper worker's craft was not an important one in Great Britain. The building industry had allowed it to fall into neglect, partly from the idea that lead was a more traditional material, and partly from the knowledge that its use would entail a heavy first cost. But to-day copper is no longer an expensive material. Its fall in price has been brought about by the greatly increased production due to the opening of new mines within the Empire, as well as by new processes inaugurated to cope with the modern demand for copper consequent upon the advance of electricity. Such expansion of production has cheapened the metal for building purposes.

Uses of Copper

The uses of copper in modern buildings are many. Leaving on one side lightning conductors, and the pipes and tubes of sanitary and purely

engineering services, copper may be employed in the construction of roofs both sloping and flat, domes, window cills, gutters, rain-water pipes, and damp-proof courses. But it is as a roofing material that copper is pre-eminently suitable, for the metal once smelted retains its properties for a practically indefinite period, and is subject to little or no corrosion.

Types of Copper Sheeting

Copper for commercial and building purposes is supplied in two grades, known as " hot rolled " and " cold rolled."

Hot-rolled copper sheeting is the proper material to specify for roofing work. It has a dead soft temper, and is obtainable in sheets up to 12 ft. long and from 6 in. wide, although, as will be seen in actual practice, smaller sheets are generally employed.

Price of Sheets

Copper sheets are priced on possessing an area of 14 sq. ft., and a thickness of not less than 24 S.W.G. Thus the average size of a sheet would be 7 ft. by 2 ft. Other sizes and thicknesses are easily obtainable, though if they run over the 14 sq. ft. area, or are thinner than 24 S.W.G., they frequently cost more to supply. But it should be remembered when ordering that sheets 8 ft. by 3 ft., although more expensive, may prove economical in the long run by the savings effected in joints, cleats, and the general labour cost of laying. Thus, on a flat roof the larger sheets will be a saving, while if the work to be done is the covering of a dome or a surface needing much cutting, the extra cost of the larger sheet will not be repaid.

Weights of Sheets

The two weights of copper sheeting in common use in this country may be shown as follows :—

Gauge	*Thickness*	*Nominal Weight*
23 S.W.G.	·024 in.	19 oz. per sq. ft.
24 S.W.G.	·022 in.	16 „ „ „ „

Hot- and Cold-rolled Sheets

As stated, hot-rolled sheets are dead soft in temper, but cold-rolled vary in three degrees, known as " hard," " half-hard," and " soft clean," the last being of the same temper as hot-rolled.

The chief use of cold-rolled copper is in the manufacture of architectural cornices and ridging where the metal has to preserve its shape, and for these purposes " half-hard " cold-rolled metal should be specified.

Tests

It is not often necessary to test copper on the job to discover whether it is hot or cold rolled, but the method employed may be of interest.

Two cuts a centimetre apart and each a centimetre long are made in the edge of a sheet; the strip between the cuts is then firmly gripped by a pair of pincers and steadily pulled over and torn towards the centre of the sheet. The pull will tear out a fragment of metal, which, if the copper be hard cold rolled, will be in the form of a blunt triangle, but if hot rolled, a long narrow one. If two sheets are tested together, care must be taken to tear each in the same direction, since copper will give a larger tear strip if tested in the direction of the rolling.

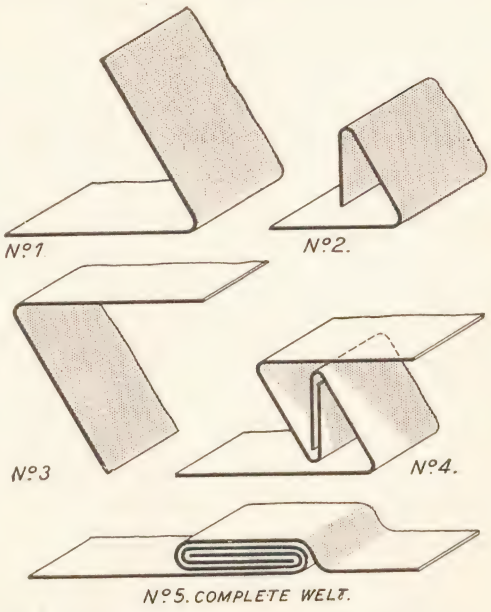


Fig. 2.—THIS SHOWS HOW A CROSS-WELT IS FORMED IN SHEET COPPER

Specification

Copper for building work should be specified to conform to the British standard specification, which lays down that the material must contain not less than 99·25 per cent. of copper, and between ·25 per cent. and ·45 per cent. of arsenic; this applies equally to copper sheets or tubes.

Copper Roofs

When properly laid, the life of a copper roof is a very long one, running into centuries. For example, the roof of Christ Church, Philadelphia, U.S.A., is over 170 years old, and said to be still in perfect preservation. In London, two of the largest copper domes are those of the reading-room at the British Museum, and the Sessions House, Old Bailey; in Liverpool, the roofs of the Mersey Dock and Harbour Board are of copper, while copper has been widely used in roofing numerous recently constructed hospitals and public buildings throughout the country.

In comparison with lead, copper has two advantages as a roofing material. The first is its weight, which is considerably less than that of lead, and thus allows the use of lighter roof timbers. A square of 100 superficial feet of copper sheeting weighs 1·1 cwt., as compared with 8·5 cwt. of 6-lb. lead, or 13 cwt. of plain tiling. The second advantage is the immunity of copper from the movement known as "creeping," which takes place in lead when laid vertically on a steep slope. Thus sharpness of pitch is immaterial to a copper-covered roof, but it is inadvisable to lay it on a flatter slope than 1 in 80.

Another advantage of copper roofing is its fire-resisting property; the melting-point of copper is 1,981° Fahr., so that it will not melt under the heat of a normal conflagration.

The following are some of the gauges and thicknesses of copper compiled by the Copper Development Association :—

*S.W.G.	Thickness	Theoretical Weight	*S.W.G.	Thickness	Theoretical Weight
	in.	lb. per super ft.		in.	lb. per super ft.
20	0·036	1·647	26	0·018	0·837
21	0·032	1·488	27	0·016	0·762
22	0·028	1·302	28	0·014	0·688
23	0·024	1·116	29	0·013	0·632
24	0·022	1·023	30	0·012	0·576
25	0·020	0·930			

* NOTE.—Imperial standard gauge (S.W.G.) differs slightly from Birmingham wire gauge (B.W.G.), but within the limits of the table the variation may be ignored.

Construction of Copper Roofs

Copper roofing sheets can be and are frequently laid on concrete, but as one of the advantages of this type of roofing is the light support required for it, the common practice is to lay the sheets on boarding, over joists or rafters. In the best work the boards should be 1-in. grooved and tongued, but quite satisfactory roofing can be done with $\frac{3}{4}$-in. or $\frac{7}{8}$-in. butt-jointed boards, provided that the upper surface is perfectly smooth. Whichever boards are used the nails must be well punched in, and the joists or supports of sufficient strength to eliminate springiness.

The boarding must be covered with a layer of either felt or building paper, nailed with copper nails.

Copper Nails

The use of copper nails is important in all copper work, as galvanic corrosion will be set up if steel and copper come in contact with one another.

The only other type of nail which seems to be satisfactory when used with copper sheeting is the hard-forged wrought-iron nail used in Scandinavian work. In selecting nails care should be taken to see that the heads lie flat on the nail without shoulders below, as when the nail is hammered home these shoulders tend to pierce and tear the sheet.

Cross-welts

The cross-joints of the sheets are frequently made in the shop, and are best done as shown (Fig. 2) by means of a double welt formed with a pair of seaming pliers. A single welt is sometimes employed in cheap work, and in America a soldered welt is occasionally used. But solder should be introduced sparingly with copper unless the parts to be so

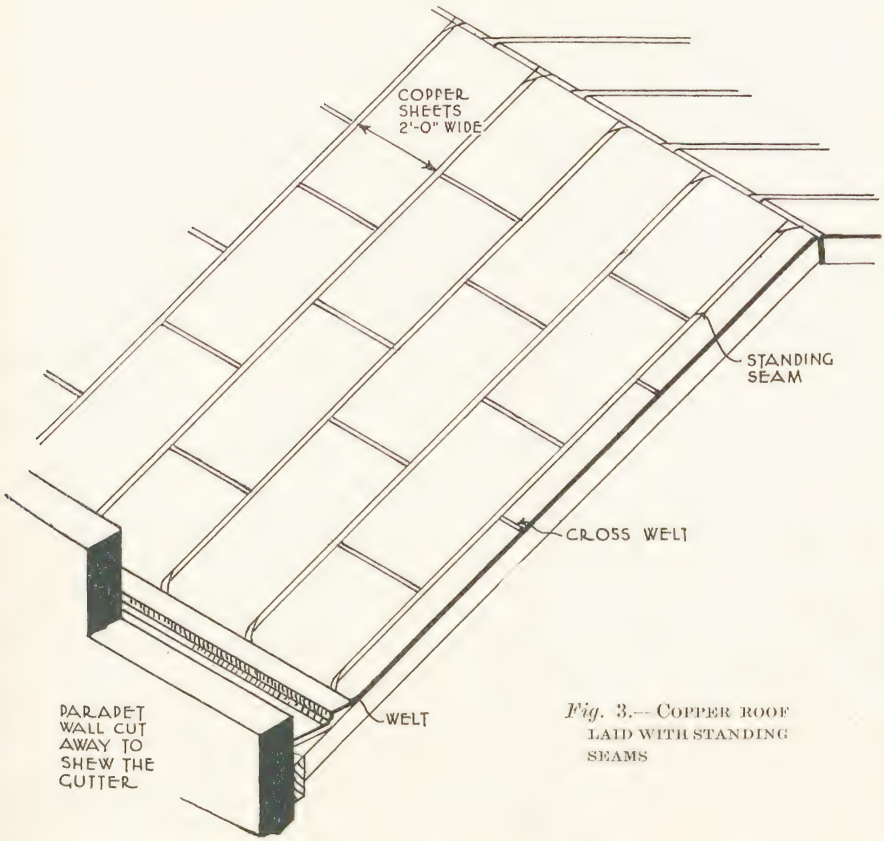


Fig. 3.—COPPER ROOF LAID WITH STANDING SEAMS

joined have been tinned, or there is danger of electrolytic action being set up.

The finished welt should be about $\frac{1}{2}$ in. wide, and this will take up about 3 in. from the length of each sheet. In the illustrations the joints are shown loosely folded for clearness, but in actual practice the sheets are beaten close together.

When the sheets have been jointed in strings they can be rolled up and sent on to the job, each length being equal to the distance from ridge to eaves, with the necessary allowance for welting at top and bottom. In arranging the sheets the cross-welts should be staggered (Fig. 3), to avoid a clumsy packing of copper over the vertical joints or seams. This can be arranged by beginning every other length with a half-sheet.

Vertical Joints

In forming the vertical joints one of two methods may be employed. These are known as the " standing seam " and " wood roll." The former

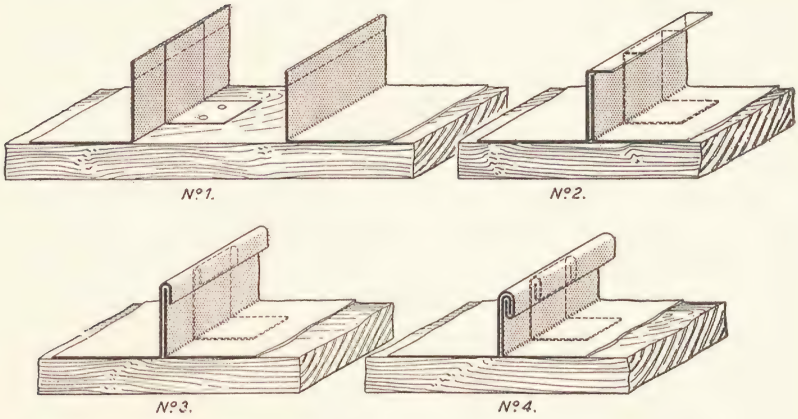


Fig. 4.—FORMATION OF A STANDING SEAM IN A COPPER ROOF

is usually employed for sloping surfaces, the latter for flat roofs, where traffic might cause damage to the thin strips of copper if not reinforced.

The purpose of these joints is two-fold : (1) to allow for the expansion of the metal due to changes of temperature, and (2) to keep the joint clear above the flow of water.

Laying usually takes place from left to right, the outer edge of the first sheet being fixed to the parapet or gable. The next sheet is then placed in position, and the edges of both turned up ready to form the standing seam. The strip is also secured to the roof by means of rectangular pieces of copper about 2 in. wide, and spaced about 12 in. apart. In America, the bottom of the cleat is often turned back to cover the nail heads, but if these are well driven and smooth this is hardly necessary.

Standing Seam

To form the standing seam the edge of the first sheet is turned up $1\frac{1}{2}$ in. all down the free side, and the second sheet is turned up $1\frac{1}{4}$ in. (Fig. 4). The two sheets are then brought together with the vertical faces at the cleats between them. In Sweden, where the standing seam joint is much used, it is the custom to paint the faces of the turn-ups with raw linseed oil before assembling, in order to prevent moisture from penetrating, but in this country, with a milder climate, it is not usually done. The extra $\frac{1}{4}$ in. of the higher turn-up is turned over the lower, and the two then bent over together once more to form the finished seam, which when complete stands up above the surface of the roof about $1\frac{1}{16}$in.

Wood Rolls

The use of wood rolls is more suitable for flats, and the manner of laying is somewhat similar to that of a lead roof. Several types of rolls are employed, but the most common in this country has a conical section

with a base of $1\frac{3}{4}$ in. and a height of $1\frac{3}{4}$ in., the top being rounded off (see Data Sheet No. 16). The rolls are first spaced out and fixed according to the width of sheets being used; 2 in. must be allowed on one side for the undercloak, and 3 in. on the other for the upper. This reduces the effective width of the sheet by about 5 in., and it is a common practice to space the rolls 2 ft. 5 in. centre to centre. Sometimes cleating strips are screwed down under the rolls at intervals and turned up at either side ready to be welted in with the roofing sheets. The projecting edge of the overcloak is first turned down over the lower, and the two then bent together to lie close along the side of the roll.

By courtesy of Fred. Braby & Co. Ltd.

Fig. 5.—SHEET COPPER ROOF LAID WITH STANDING SEAMS ON A FLAT PITCH

The cross-welts are staggered. Note the method of turning over the seams at eaves. Notice also the copper guttering, with stiffeners at intervals.

Square Rolls

Another type of wood roll, much used in Scotland and America, has a slightly battered rectangular section. The sheets are turned up against these sides and have horizontal projecting flanges (Fig. 6). Over these flanges is slipped an already prepared capping which when in place is hammered down along the sides of the roll.

Copper Flashings

The junction between the roof and a parapet is best formed by turning up the sheet against the brickwork and covering it with a flashing tucked into a mortar joint (Fig. 6A), much in the way a lead flashing is made. But in addition S-shaped pieces should be slipped at intervals

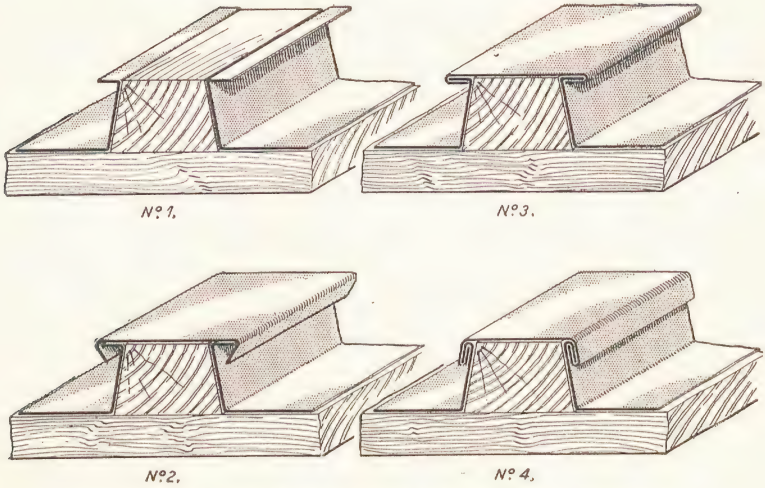


Fig. 6.—STAGES IN FORMING A FLAT-TOP WOOD ROLL

between the sheet and flashing, to prevent the latter lifting in a wind and exposing the joint.

Flashing to Chimney Stack

Where a standing seam strikes against a chimney stack the process of making a joint is more complicated. The ends of the two sheets are turned up and cut back as shown in the illustration (Fig. 7). The sheets are then placed together—the cut portions of the parts turned up sliding over one another—and the standing seam completed in the usual manner. At the end of the seam a specially welded saddle-piece is placed over the welt, and the top of the vertical upstands turned down over it. The whole is then covered with a vertical flashing as already described.

The finish of a wood roll against a stack can be carried out in a similar manner. Where the copper sheets finish over the eaves the standing seams are turned over and dressed flat against the vertical face or over the gutter (Fig. 8), but a wood roll finish is not so simple.

Flashing at Eaves

A flashing sheet running along the eaves is prepared with portions cut to cover the ends of the rolls, and the intermediate portions folded with an S-fold to lie on the boarding (Fig. 9). The ends of the wood rolls are not cut immediately over the drip, but set back slightly, and the margin covered by the flashing sheet. The roofing sheets are then brought forward, welted with the cut gusset-piece over the ends of the rolls, and tucked into the fold on the flat portion of the flashing lying on the roof boarding.

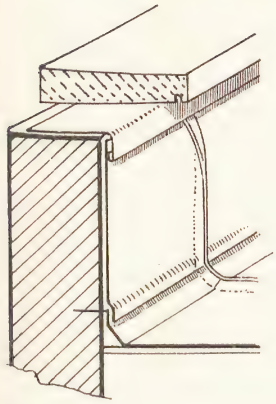
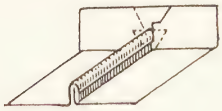
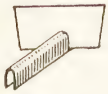


Fig. 6A.—FLASHING TO A PARAPET WALL





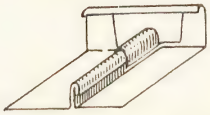


Fig. 7.—END OF SEAM AGAINST WALL

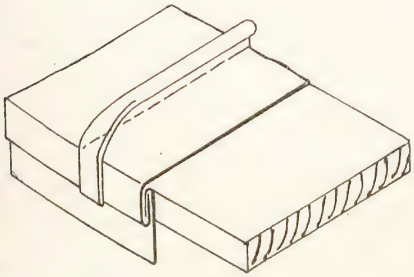


Fig. 8.—FINISH OF STANDING SEAM AT EAVES

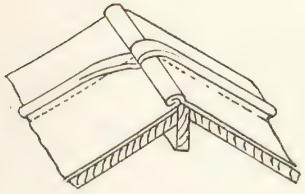


Fig. 10.—FINISH OF STANDING SEAM AT RIDGE

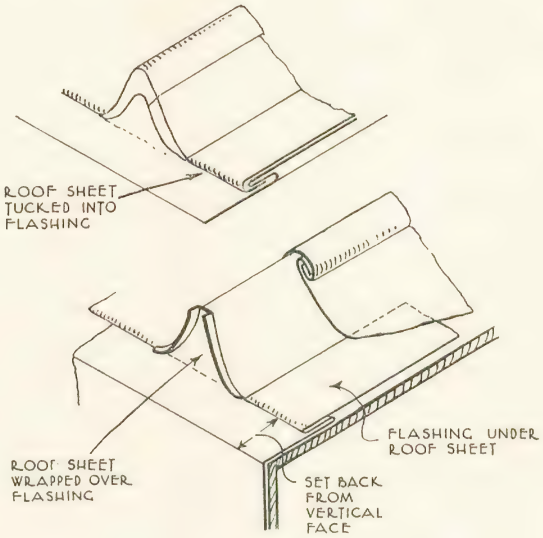


Fig. 9 (*right*).—DETAIL OF FLASHING AT END OF WOOD ROLL

Ridges

At the ridge the standing seams may be either welted over with the sheets, provided that the roof ends in a smooth, rounded apex, or, if the ridge piece projects, a shaped ridge moulding of cold-rolled copper may be used (Figs. 10, 11, and 12). Such a finish is equally suitable for covering a simple hip, but where wood rolls intersect on a hip the most workmanlike finish is one where the hip roll itself stands higher than those intersecting into it. The welts are then carried up from the lower rolls into the higher.

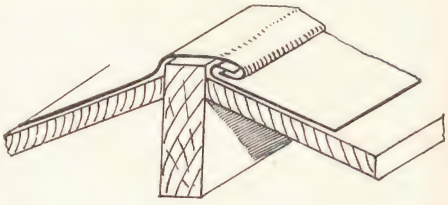


Fig. 11.—METHOD OF FORMING RIDGE IN COPPER SHEET

Copper Welding

The process of welding the joints in copper roofing is not at present a common practice. But it is likely to become more so in the future, and a few notes on the process may be useful.

Welding copper sheets is carried out by the oxy-acetylene process, and two methods of doing the work are employed. Either the metal itself is fused down to make the joint, or a filler rod of copper or some metal of a lower melting-point is fused over the joints of the sheets. Where the copper is itself fused the method is known as "autogenous," and where another metal is fused over the copper it is termed "bronze welding"; the actual fusing of the sheets themselves without a filler rod is termed "flash welding."

Deoxidised copper is obtainable, and should be specially ordered where welding is contemplated, unless bronze filler-rod welding is intended, when ordinary copper sheets may be employed, as the heating necessary to form the joint will be below the melting-point of the copper sheets.

Light-gauge Roofing

The Copper and Brass Extended Uses Council has devised and patented an original type of roof suitable for a pitch of 8° and over, called for convenience the "Council" roof (Fig. 13). This should not be confused with the idea of borough or rural councils, which the name usually implies in this country.

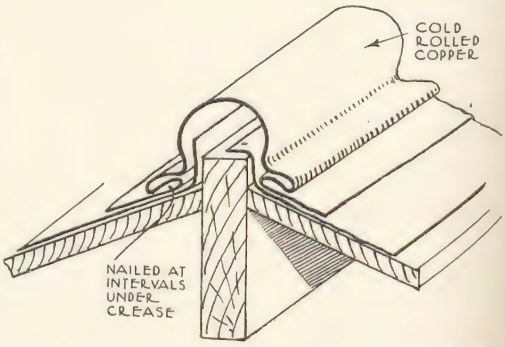


Fig. 12.—ANOTHER METHOD OF FORMING RIDGE IN COPPER SHEET

The roof is composed of strips of 30 S.W.G. cold-rolled

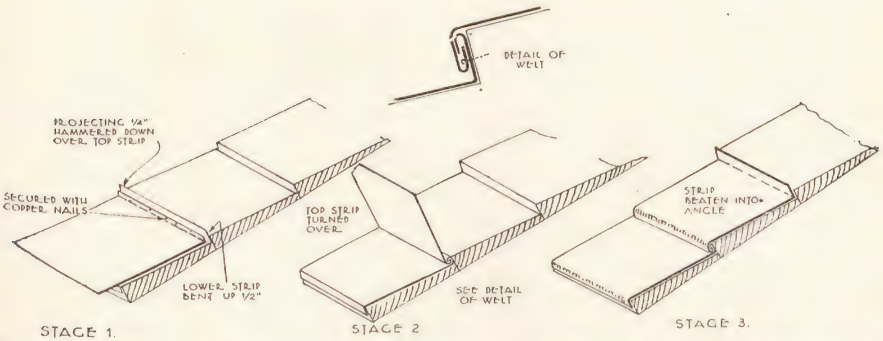


Fig. 13.—Light copper strip roofing on feather edge boarding, patented by Copper and Brass Extended Uses Council

"soft clean" type. These are laid on feather-edge boarding with the thick end downward. The strips have the upper edge turned up before laying. The first sheet is fixed at the eaves and turned up against the lower edge of the next feather-edge board. The next strip is placed along on the top and the two sheets secured into the boarding (Fig. 13). The upper edge of the lower sheet is then welted down over the upper, and the latter completely turned over on to the board above and dressed into the lower edge of the next board. Another sheet is then laid along on top of this sheet, and the process repeated up to the top of the roof. In such light gauge the expansion is taken up in the metal itself without the need of expansion joints.

Welded Joints

In welding roofing sheets the edges are turned up and brought together much in the same manner as when forming a welt, and the edges are then fused down by running the flame of a blow-lamp along them (Fig. 15). As copper quickly takes up and disperses heat, the part to be welded should first be warmed up with the lamp flame to prevent the metal drawing out the heat from the blow-pipe as it passes along the edges to be fused. Welding anchors the edges of the sheets, so that expansion has to be allowed for in the turn-up, as shown in the illustrations, where the over-all height is $\frac{1}{2}$ in., having $\frac{1}{4}$-in. run-down for welding, while in the second example the upper $\frac{1}{8}$ in. is taken up with the filler rod.

When welding is to be carried out the copper sheets should be laid on asbestos rather than on roof paper or felt; if this is not laid over the whole roof it should at least be put under the welded joints.

Welding is also employed for forming flashings, chimney backs, gutters, cess-pools, and water tanks.

Copper Guttering

Box guttering and cess-pools do not need any special remarks, as they are formed in a similar manner to lead, with the angles usually bronze

By courtesy of Copper Development Assn.

Fig. 14.—LAYING COPPER ROOF SHEETING

The uncovered wood roll in foreground shows copper cleats ready for fixing sheet, also the bituminous felt on which the roof is laid. (*Athenæum Club, London.*)

welded in situ. But copper is a good material for eaves gutters if carefully constructed, and one advantage it possesses over cast iron is that it does not require periodical painting. The best type of metal for the purpose is cold-rolled "half-hard," generally of 22 S.W.G., and this can be had in strips from 2 in. wide and upwards, which dispenses with the labour of cutting up large sheets. In making a gutter both edges should be beaded to give stiffness, and special stiffeners should be inserted at intervals across the gutter clear of the water flow (Fig. 16). Guttering should be made in lengths of between 6 ft. and 10 ft., as these are convenient to handle.

The joints between the lengths may be formed with a plain overlap in the direction of fall, or with a special expansion slip fitted to the ends, at about 50-ft. intervals. A certain amount of soldering is necessary at stopped ends and on mitres, and where done should have the copper previously tinned.

All gutter brackets, nails, and spikes must be of copper, to avoid galvanic action, but the chief danger with this type of guttering where hung at the ends of projecting eaves comes from the blows or weight of ladders placed against their sides by careless workmen; these may crush the gutter and thus check the flow of water from the roof.

In Sweden this is obviated by forming the gutter with vertical boards placed some inches above the eaves to direct the rain-water into a swan's-neck carried over the edge to the rain-water head below (Fig. 18).

Architects may object to the appearance, but actually it forms a very practical solution to the gutter problem.

By courtesy of Copper Development Assn.

Fig. 14A.—FORMING THE SEAMS OVER WOOD ROLLS ON A COPPER ROOF

Copper Protective Coating or Patina

In absolutely pure air bright copper will oxidise to a dark colour in a short time. But such conditions exist only in the laboratory, and the ordinary atmosphere of towns contains certain chemical impurities, notably sulphur, which act upon the metal and produce a basic sulphate on the surface. This is the green patina so distinctive of copper roofing. It takes time for the sheets to acquire this colour, and ten years may elapse before it fully develops, but it is a valuable protective, for after about half a century no further action takes place, and the coating preserves the copper underneath from further decay for all time.

The formation of the patina can be hastened by spraying with an ammonium sulphate solution prepared in accordance with the formula of the Copper Development Association. Another formula, recommended by the Copper and Brass Extended Uses Council, consists of 1 lb. of sal ammoniac dissolved in 5 gal. of water, and applied with a brush, which is then cleaned off after 24 hours by spraying with clean water.

The patina is sometimes loosely referred to as "verdigris," but is an entirely different product; verdigris requires acetic acid, and this is not found in the air in sufficient quantities to produce a deposit of acetate of copper on roofs.

Ultra Light-gauge Roofing

If the exact amount of reduction in the thickness of the copper sheet due to the formation of the patina could be precisely ascertained, it would

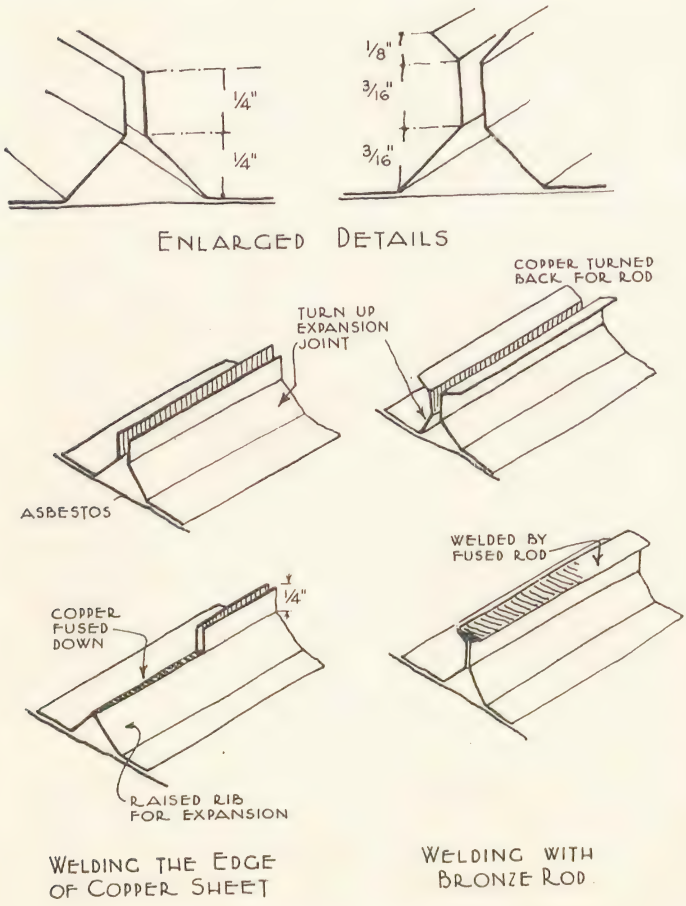


Fig. 15.—WELDED COPPER JOINTS

then be possible to determine the thinnest possible sheet that could be used for covering a roof, for, as already stated, after a certain period no further corrosion takes place.

It is along these lines that experiments in light-gauge copper roofing are taking place, and sheets as thin as 3 oz. to the square foot have been used in America, but at present these are not much in favour in this country.

The sheets are formed of cold-rolled copper, and are employed on a fabric backing usually impregnated with asphalte—they are, in fact, almost a copper foil. The sheets are usually 2 ft. in width, and can be had in strips up to 150 ft., but at present one of the chief difficulties has been in providing a satisfactory adhesive to stick the copper sheet down to the undercoating.

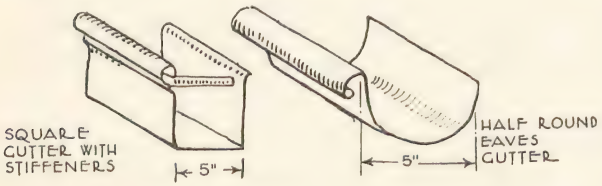


Fig. 16.—COPPER GUTTERING

When a backed sheet is made, a free edge of copper is sometimes left all round, which can be turned up into seams

By courtesy of Copper Development Assn

Fig. 17.—HOUSES IN STOCKHOLM

Swedish copper roof, showing method of forming guttering at eaves.

and welted very easily. But expansion in so thin a metal is very small, and the sheets are sometimes stuck down one upon another, the expansion being taken up in the sheets themselves.

Such roofing, it is claimed, is equally suitable for flats or for steep pitches, provided that the jointing is well made and watertight.

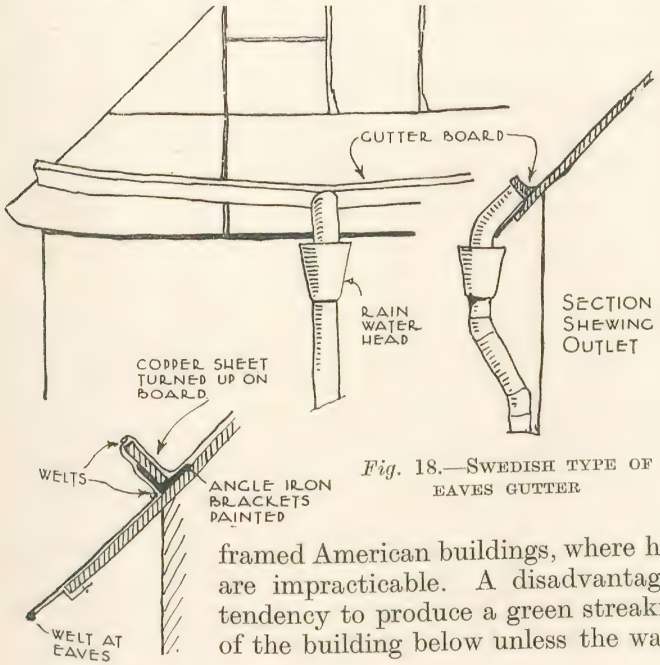


Fig. 18.—SWEDISH TYPE OF EAVES GUTTER

Cornices

Sheet-copper cornices are probably "bad architecture" when their profile is deliberately designed in imitation of stone, but they are employed on many high, steel-framed American buildings, where heavy stone cornices are impracticable. A disadvantage of copper is the tendency to produce a green streakiness down the face of the building below unless the water is thrown clear.

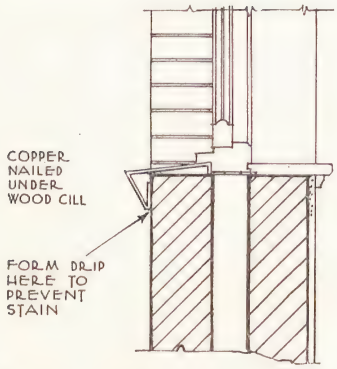


Fig. 19.—COPPER STRIP AS CILL TO WINDOW

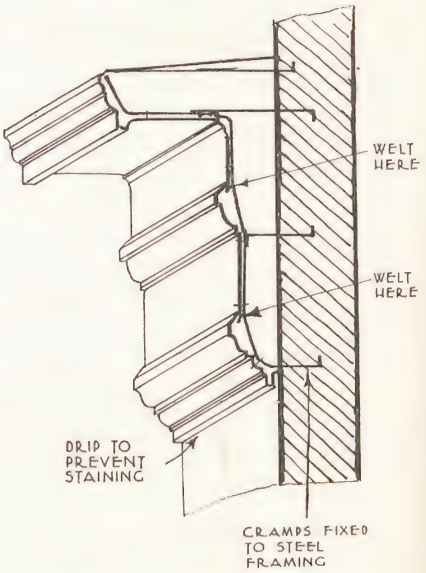


Fig. 20.—COPPER CORNICE

Cold-rolled copper should be used for cornices, and the material folded with a cramp folder. Sections should be jointed with a 3-in. overlap, to allow for temperature variations, and in general practice lengths should not exceed 6 ft. All rivets and bolts should have loose holes and be provided with washers, for in such exposed situations considerable movement in the metal may be expected (Fig. 20).

Copper Cills

In Scandinavia it is a common practice to put copper cills to the windows. The sketch (Fig. 19) shows a usual type, which throws the water clear of the wall, but with this kind of cill it is almost impossible to avoid a streak of green " run-off " forming on the wall at either end of the window opening. In wood-framed buildings these cills may be useful, but it is doubtful if they have any advantage over the brick or tile cills used in this country in normal building practice.

Damp-proof Courses

Copper strips can be obtained cut to the various widths of brick walls, in rolls up to 50 ft. in length. Cold-rolled copper, " soft clean," of 24 S.W.G., is the best for this purpose.

Although copper is immune from corrosion by limes or cements used in mortars, and will adapt itself to building settlements without tearing or cracking, it is sometimes passed over in favour of other materials on account of its supposed low frictional resistance. Under a load of 2 tons per square foot it requires a pressure of 470 lb. per square foot to slide the wall off a copper sheet, compared with 830 lb. on a lead sheet. But such a side thrust is unlikely in practice, and may be ignored in ordinary building design.

TEMPORARY TIMBER CENTERING FOR ARCHES

MANY variations in " centres " are required between the simple " turning piece " in Fig. 1 and the 20-ft. framed centre in Fig. 11. Their shapes and construction may vary, but their purposes are alike, viz. to give temporary support to an arch until it is capable of supporting itself.

Load on Centres

The shaded part in Fig. 2 shows the area of walling actually supported by the lintel. The mass of brickwork above the shaded portion, and between the broken lines, is transferred to the piers by the corbelling of the joints above. If an arch, following approximately the line of the corbelling, replaced the lintel, it would carry practically nothing but its own weight. This is true when the mortar in which the bricks are laid is set, but until that takes place a certain amount of weight must be carried by some temporary support.

Form of Arch Influences Load

Fig. 3A shows an equilateral arch which will throw little weight on the centre, the curve of the " intrados " being steep. The centre in Fig. 3B, having a flatter curve, will be subjected to a greater downward strain. The semicircular centre in Fig. 3C is something between the other two.

Construction of Centres

The shape and size of the opening will govern the number of parts which are required to make up the " rib " and the number of parts will decide the bracing. Fig. 3A shows a centre in which only two pieces are necessary for the complete rib, each piece being cut from a board 9 in. wide. In Fig. 3B four pieces are required, whilst in Fig. 3C six pieces are shown, assuming all the pieces to be cut from 9-in. stuff. By using wider boards the number of pieces forming a rib could be reduced, but this would mean more " cutting to waste," therefore it is less economical.

Stresses on Centres

When the " voussoirs " at the " haunches " of an arch, as in Fig. 3C, are placed in position there is a tendency for the " crown " to be forced

Fig. 1.—WOODEN CENTRE FOR FORMING ARCH OF FIREPLACE OPENING

with boarding 1 in. to $1\frac{1}{4}$ in. in thickness.

Setting Out Ribs

If the curve is a segment of a circle, set out the span X Y as shown in Fig. 4; at Z, the middle point of the span, draw Z C at right angles to X Y and mark off Z C equal to the rise. Join X C and Y C—A is the middle point of X C. Draw A D at right angles to X C, and produce to cut C Z produced to D—D is the centre for the curve. As a check, draw from B a line at right angles to C Y; it upwards, so it must be tied down as suggested by A B. If the tie were weak it would also tend to bend upwards, so it must be kept down by the braces C B and D B, which the loading at the haunches will accomplish.

Rigidity

To withstand distortion at different stages of loading, a centre must be well braced. If the braces and ties are well placed to take the strain, even large centres (for openings in walls) may be constructed

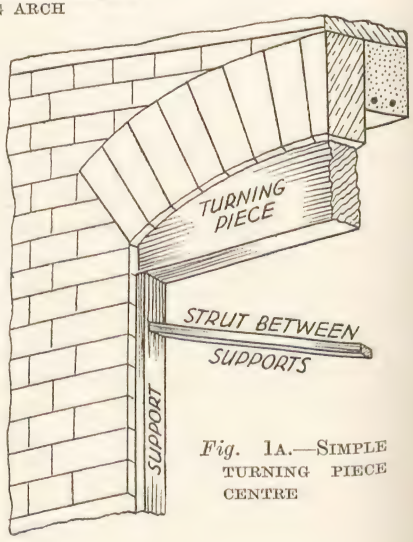


Fig. 1A.—SIMPLE TURNING PIECE CENTRE

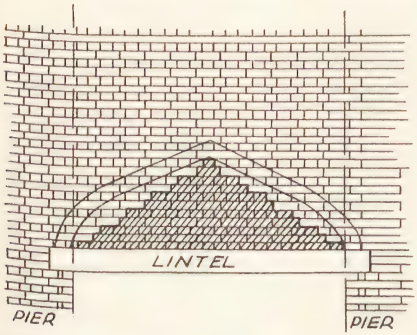
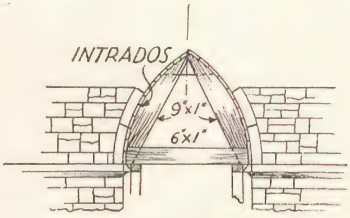
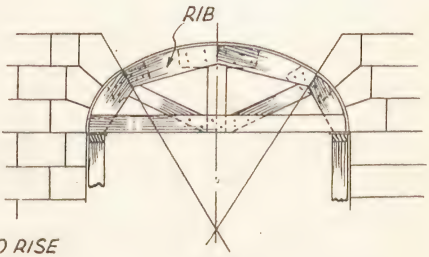


Fig. 2.—ILLUSTRATING PRINCIPLE OF ARCH

If an arch, following approximately the line of the corbelling, replaced the lintel, it would carry practically nothing but its own weight—after the mortar had set.





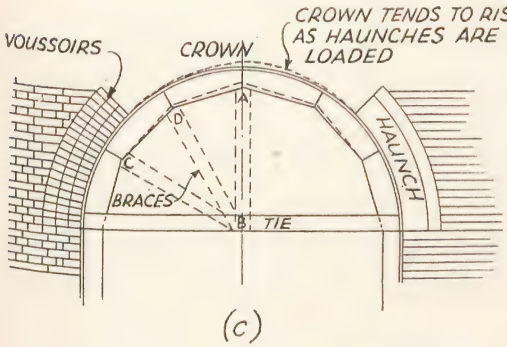


Fig. 3.—HOW FORM OF ARCH INFLUENCES THE LOAD ON THE CENTRE

(*a*) An equilateral arch throws little weight on the centre. (*b*) Semi-elliptical centre is subjected to the most downward strain. (*c*) Semi-circular centre is subjected to weight something between that in (*a*) and (*b*).

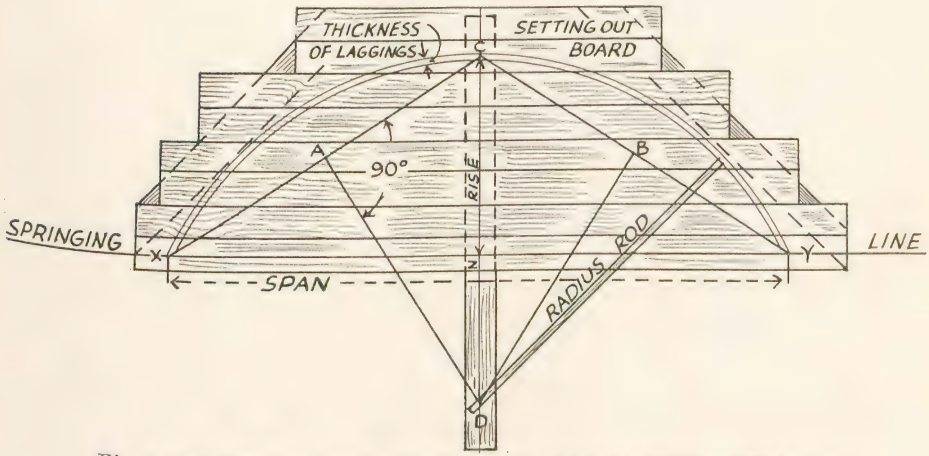


Fig. 4.—SETTING OUT RIBS FOR CIRCULAR CENTRE ON SETTING-OUT BOARD

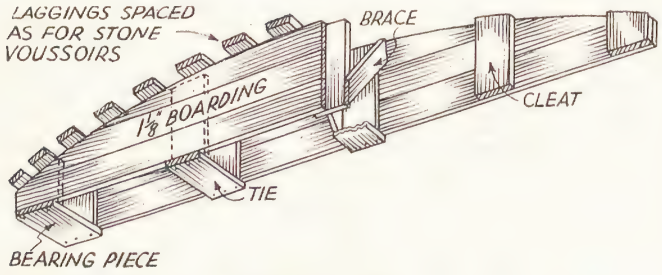


Fig. 5.—SOLID-RIB CENTRE FOR ARCHES WITH LOW RISE IN RELATION TO SPAN

should cut C Z, produced, at D. Fix a thin lath with a bradawl at D, cut it to the length D C less the thickness of the lagging. This will be the radius rod for the curve.

Solid-rib Centres

For arches with a low rise in relation to the span, solid-rib centres are best (see Fig. 5). They are rigid and well suited to take heavy loading.

CONCENTRIC ARCHES

Fig. 6 shows a centre of two concentric rings suitable for a door or window opening with a rebate for the frame. This centre would be

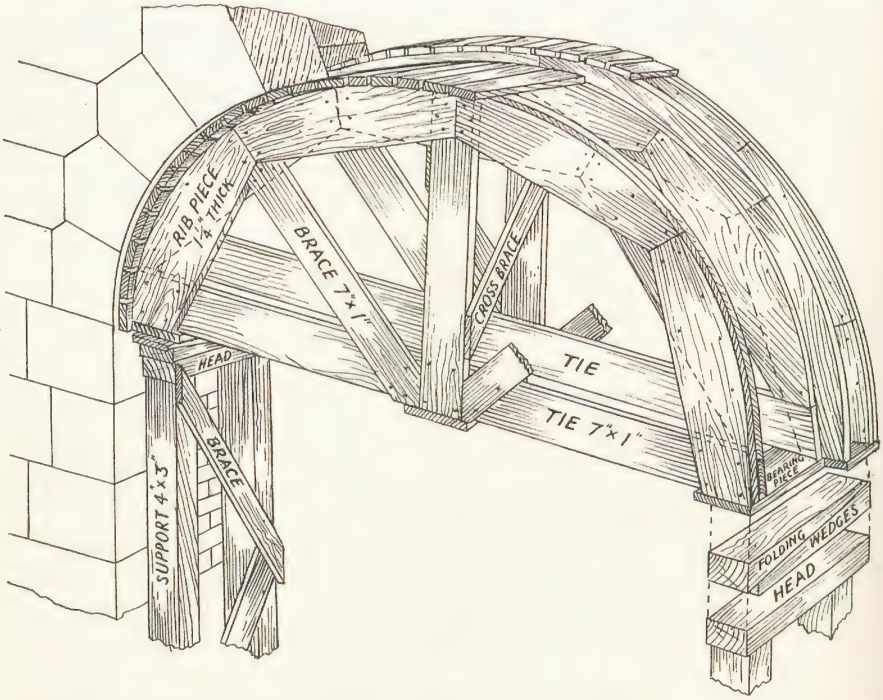


Fig. 6.—CENTRE FOR CONCENTRIC ARCHES

Suitable for door or window opening with a rebate for the frame, and for spans of about 6 ft. to 8 ft. Note methods of supporting and easing by folding wedges.

Fig. 6A (*right*).—SEMICIRCULAR ARCH ENTRANCE TO CHURCH AT FOXROCK, CO. DUBLIN
(*Architect: John J. Robinson, F.R.I.B.A.*)

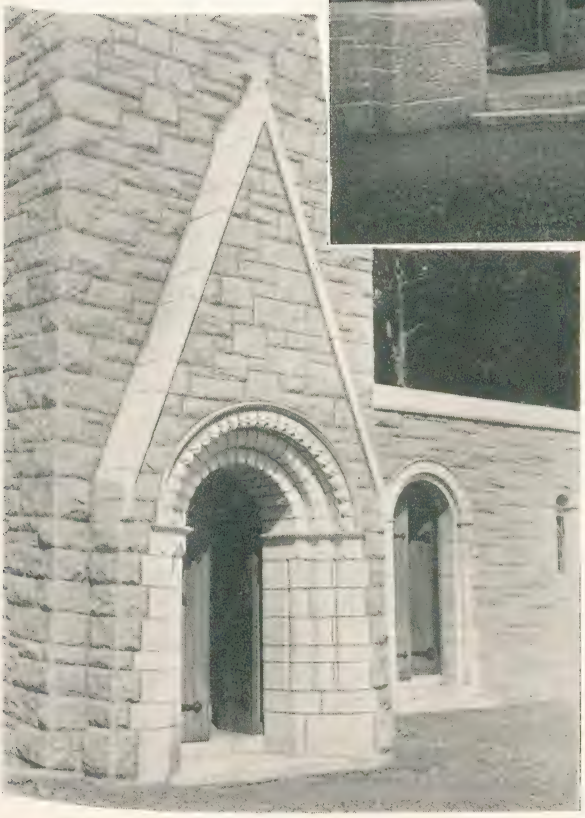


Fig. 6B (*left*).—SEMICIRCULAR ARCH ENTRANCE AT BASE OF TOWER OF CHURCH AT LUSK, CO. DUBLIN
(*Architect: John J. Robinson, F.R.I.B.A.*)

Fig. 6c.—BIRMINGHAM MUNICIPAL BANK—MAIN ENTRANCE ARCH

Note that Portland stone is used. The door is of high-class enriched bronze metal. The base of the building is of axed Cornish granite. (*Architect: T. Cecil Howitt, F.R.I.B.A.*)

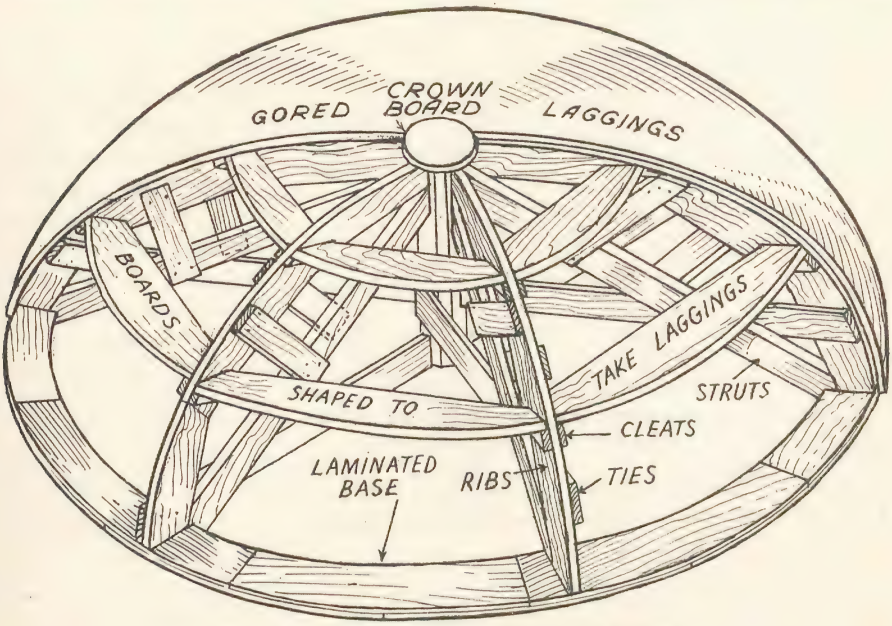


Fig. 7.—CENTRE FOR SEMI-ELLIPTICAL DOME

suitable for spans of about 6 ft. to 8 ft. The methods of supporting, and for easing by folding wedges, are shown.

Domes

The sketch in Fig. 7 shows the general construction of a semi-elliptical dome 10 ft. in diameter. The half-section in Fig. 8 shows the construction of one rib and the method of obtaining the shape of the template for the gored laggings. Step off a number of points as 1, 2, . . . 9, 10, as indicated on the section. Project these points down to the centre-line of the plan. If the laggings are to be cut from, say, 6-in. boards, set off this width half on each side of the centre-line and join to the point 10 (the centre of the dome). On the line *a a* step off 1, 2, . . . 9, 10, equal to those on the section. Mark off the width at 1 on *a a* equal to that at 1 on the plan ; make 2 equal to 2 on the plan, and so on. Cut the template at the point 9, which is the point where it meets the crown board. Cutting the template at the point 9 will give sufficient width for nailing, and the bevelled ends under the crown board give additional grip.

Plaster Centre for Niche Head

Fig. 9 shows a centre suitable for a niche head in gauged brickwork, semicircular in both plan and elevation. The space between the front and base boards is packed with shavings kept in place by a piece of

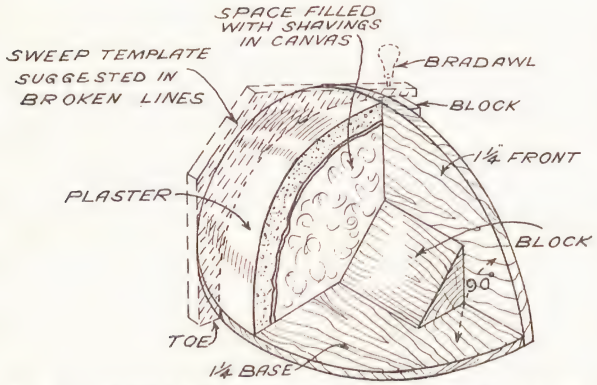


Fig. 9.—CENTRE FOR NICHE HEAD IN GAUGED BRICKWORK SEMICIRCULAR IN BOTH PLAN AND ELEVATION

canvas or expanded metal lathing, tacked to the boards. Plaster is then spread over, and a sweep template, cut to the quarter of a circle, is turned round the bradawl as a pivot, at the same time keeping the toe of the template tight against the base board.

Inverted Arches

The method of cutting the bed bricks for an inverted arch is shown in Fig. 10. The brickwork on either side is "raked" back until the horizontal centre line

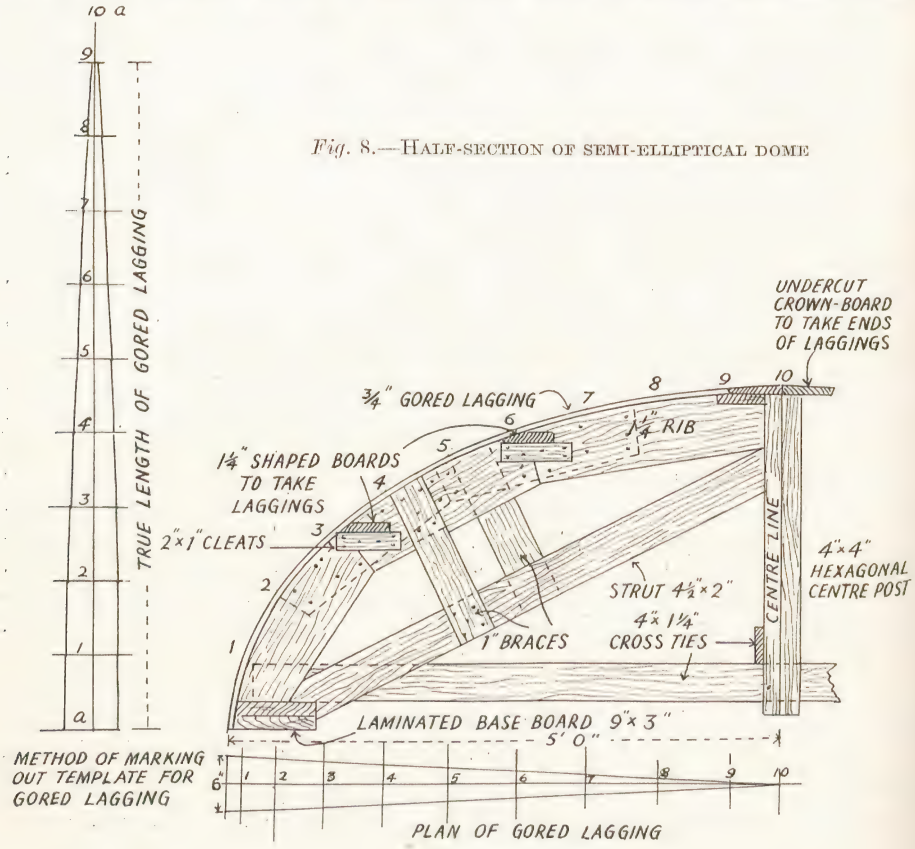


Fig. 8.—HALF-SECTION OF SEMI-ELLIPTICAL DOME

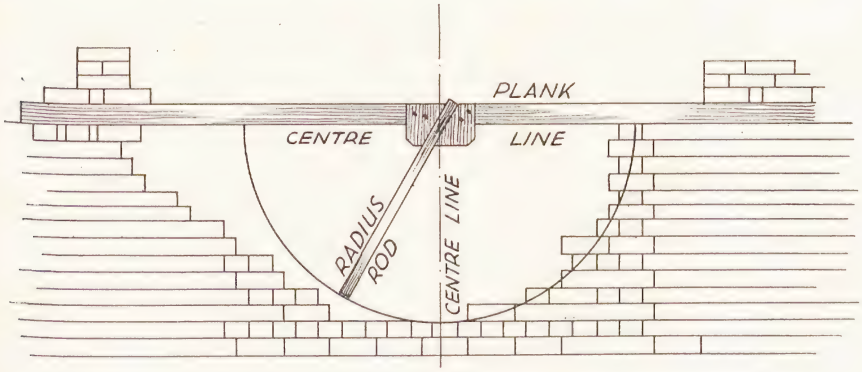


Fig. 10.—METHOD OF MARKING OUT INVERTED ARCHES

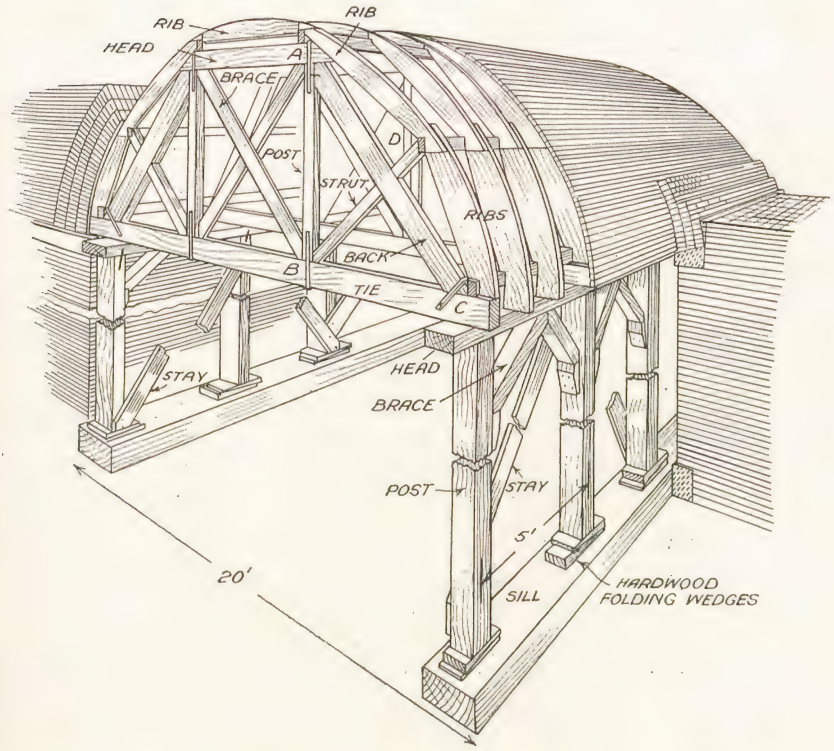


Fig. 11.—FRAMED CENTERING FOR BRICK BRIDGE OR TUNNEL
Details of the joints are shown in Fig. 11A.

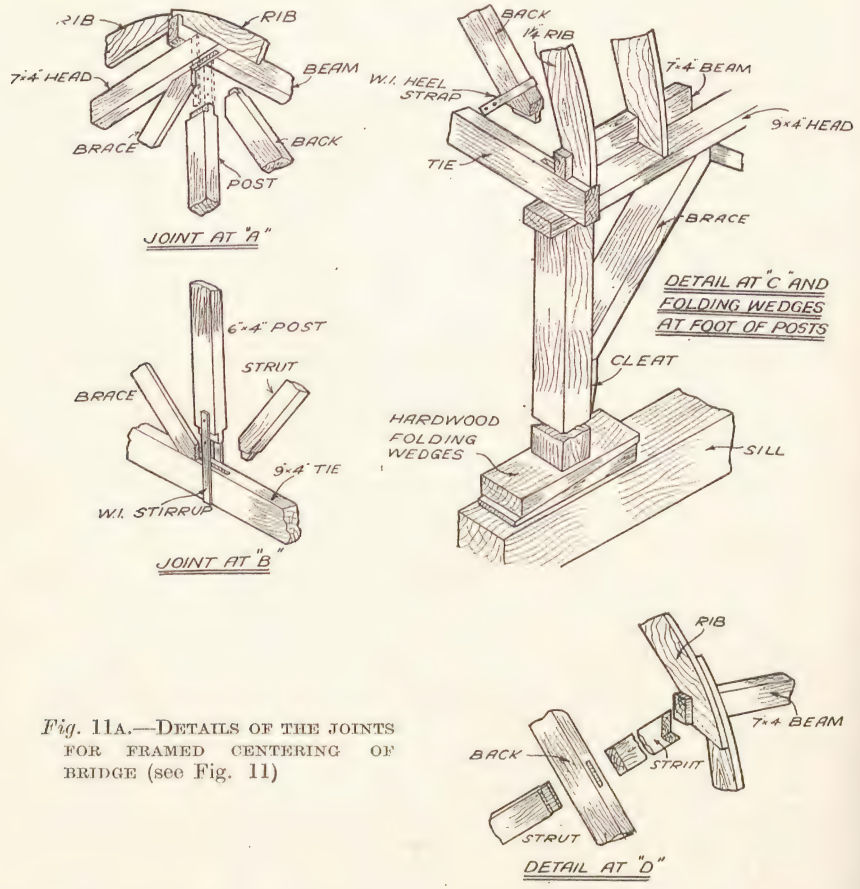


Fig. 11A.—DETAILS OF THE JOINTS FOR FRAMED CENTERING OF BRIDGE (see Fig. 11)

is reached. A plank is then laid across, weighted to keep it in position, and the vertical centre-line marked. As the bricks come within reach of the rod they are "scribed"—allowance being made for the thickness of the mortar joint, removed for cutting, and finally bedded and again tested.

Framed Centres

When centering is required for works such as brick tunnels or bridges, the ribs are spaced out on beams, which are in turn supported on frames spaced to suit the weight to be carried. The sketch in Fig. 11 shows the general construction of a framed centre. Fig. 11A gives details of the joints.

Vaulting

Fig. 12 shows a sketch of the centres for the cross-, wall, and diagonal ribs in position. These would have to be "racked" together to keep

Fig. 11B.—EDGE HILL TRAINING COLLEGE, ORMSKIRK

Showing arch detail at main entrance and the Corinthian columns, surmounted by the Lancashire County Council Coat of Arms. (*Architect : Stephen Wilkinson, F.R.I.B.A., A.F.C.*)

Fig. 11c.—ARCHES IN THE CHURCH OF THE GOOD SHEPHERD, ROMFORD

Walls and arches faced with sand-lime bricks. Windows are of Monks Park Bath stone. Roof is of British Columbian pine. (*Architects: J. E. Newberry, F.R.I.B.A., and C. W. Fowler, A.R.I.B.A.*)

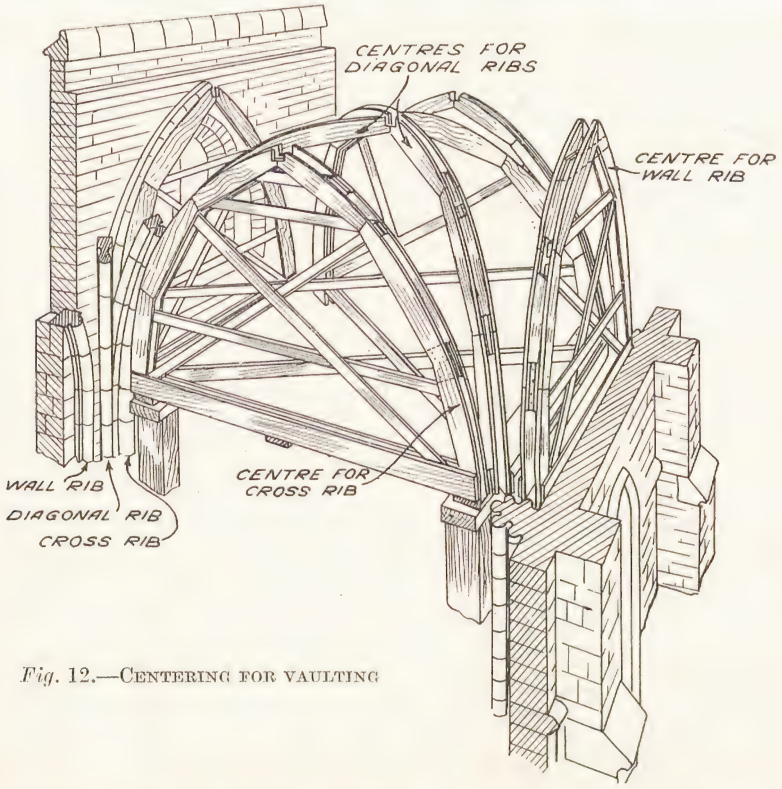


Fig. 12.—CENTERING FOR VAULTING

them upright; the racks are not shown in the sketch. In order that the diagonal ribs shall be straight on plan, the curves of the centres for the cross-rib and wall rib must be such that a given point on their curves shall be at the same level. For example, the heights of X′ (Fig. 12A) above the springing-line on the cross-rib and the wall rib must be the same, so that when the centres are erected horizontal lines from these points would intersect at Y on the diagonal rib. The same must be the case for any other point.

Intersecting Arches of Equal Height but Varying Span

The span and rise of the centre for the cross-rib are fixed, and the centre from which the curve is drawn determined as explained in Fig. 4. This centre may then be constructed.

The rise of the wall-rib centre is the same, but the span is different; therefore a curve must be found to satisfy the conditions with regard to the diagonal line being straight on plan. Divide half the span of the cross-rib centre into any number of equal parts 1, 2, . . . 8, 9, and draw ordinates parallel to the centre line; these ordinates meet the curve at

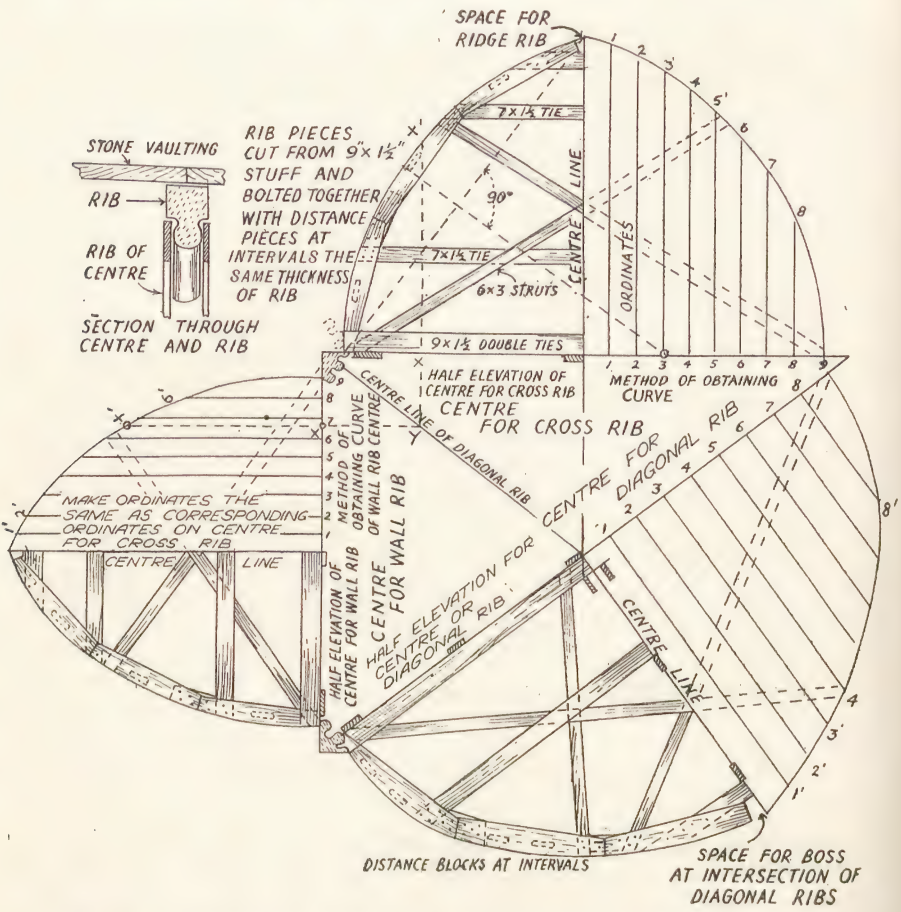


Fig. 12A.—DETAILS FOR CROSS WALL AND DIAGONAL CENTRES FOR VAULTING

1′, 2′, . . . 8′. Divide half the span for the wall-rib into the same number of parts, and again draw ordinates. Mark off the ordinates on the wall-rib centre the same length as corresponding ordinates on the cross-rib centre, and with a thin lath draw the curve through the points. The same procedure will give the correct curvature for the diagonal-rib centres.

Severies or Panels

The spaces between adjacent ribs are filled in with slabs of stone; these are slightly arched, and an adjustable support is shown in Fig. 12C. Where the ribs are close together, as at the springing-line, one stone slab may bridge the span, but as the work rises and the span increases the

Fig. 12B.—SEACOMBE FERRY BUILDING, COUNTY BOROUGH OF WALLASEY
The entrance arch of Portland stone. The clock tower is carried out in a graded colouring of rustic brick. (*Architect : L. St. G. Wilkinson, M.Sc., M.Inst.C.E.*)

adjustable centres are laid between the ribs (the iron nib resting on the top) and the slabs bedded. The centres are then withdrawn and moved up to support the next course of slabs. The iron nibs should equal

approximately the thickness of the bed joint.

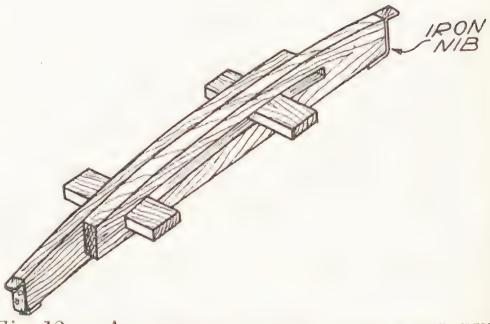


Fig. 12c.—ADJUSTABLE CURVED TEMPORARY CENTRE FOR SEVERIES BETWEEN RIBS OF VAULTING

Easing Centres

When any arched structure is finished, the centres should be slightly eased to allow the work to "bed down" firmly. The folding wedges, as shown in Figs. 6 and 11, are usually employed, but Fig. 13 shows another type which gives finer adjustment. The maximum vertical drop which can be obtained by stepped folding wedges is small, but well suited for heavy loads. It is advisable to grease folding wedges of any kind, but especially stepped wedges, which are more liable to hang back when eased and then slip suddenly, tending to jar the work. The sand piston (Fig. 14) is another kind of support for heavy work. A turned hardwood block fits into a hollow iron cylinder partly filled with fine sand. Small holes round the sides of the iron cylinder are fitted with plugs, which when withdrawn allow the sand to escape and the turned wood block to settle down into the cylinder. For repair work, centres may have to be placed under arches already built, to give temporary support, and screw-jacks will be preferable to folding wedges : they give a steadier lift. Care must be taken when pulling on the tommy-bar that the jack is not thrown off the plumb, thus causing eccentric loading.

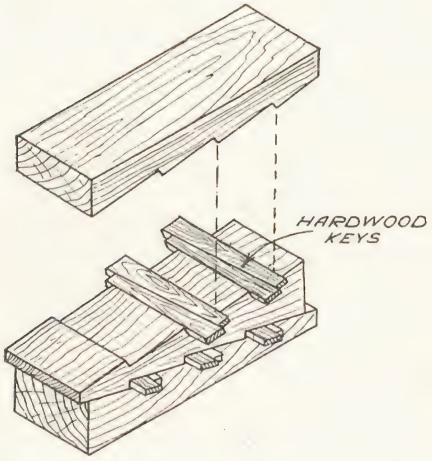


Fig. 13.—STEPPED FOLDING WEDGES

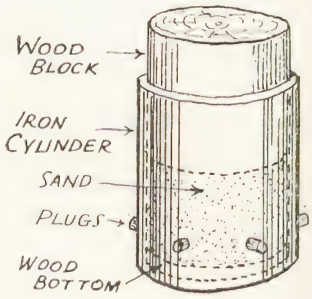


Fig. 14.—THE SAND PISTON—ANOTHER TYPE OF SUPPORT FOR HEAVY WORK

LININGS, ARCHITRAVES, AND DADOS

TYPES AND FIXINGS

THE word " lining " is the term applied to the more or less decorative woodwork which covers the jambs and under sides of lintels in door and window openings, protecting the angles, and, in the case of doorways, forming the framework to which the door is hung. " Architrave," similarly, is a term applied to the surround, usually moulded, which forms the frame of a door, window, or any other opening or recess.

Materials Used

Linings and architraves may be made of softwoods such as fir, pine, etc., or hardwoods such as oak, teak, mahogany, walnut, etc. The latter woods are used, where funds are available, for greater elaboration in the decorative woodwork, and especially in conjunction with panelled wall surfaces.

Use of Softwoods

The softwoods are usually employed where decorative treatment at a moderate cost is to be effected by the use of coloured painted surfaces. Delicate mouldings are not appropriate, as the periodical application of coats of paint soon fills up the smaller members of the mouldings and the beauty of their contours is marred and eventually lost.

When Hardwoods Are Employed

The cost of hardwoods prohibits their use except in the best class of work. They are used because of their ability to stand severe changes of climatic conditions without undue shrinkage and warping; for the beauty of their grained surfaces, more fully exploited by judicious sawing of the logs; for their apt reception of the smaller and finer parts of mouldings, and their ready acceptance of a high polish.

Certain softwoods, if carefully selected, also readily receive the delicate workmanship of refined mouldings, but the finer parts are very susceptible to easy damage from ordinary wear and tear, and their other qualities generally suffer by comparison with hardwoods.

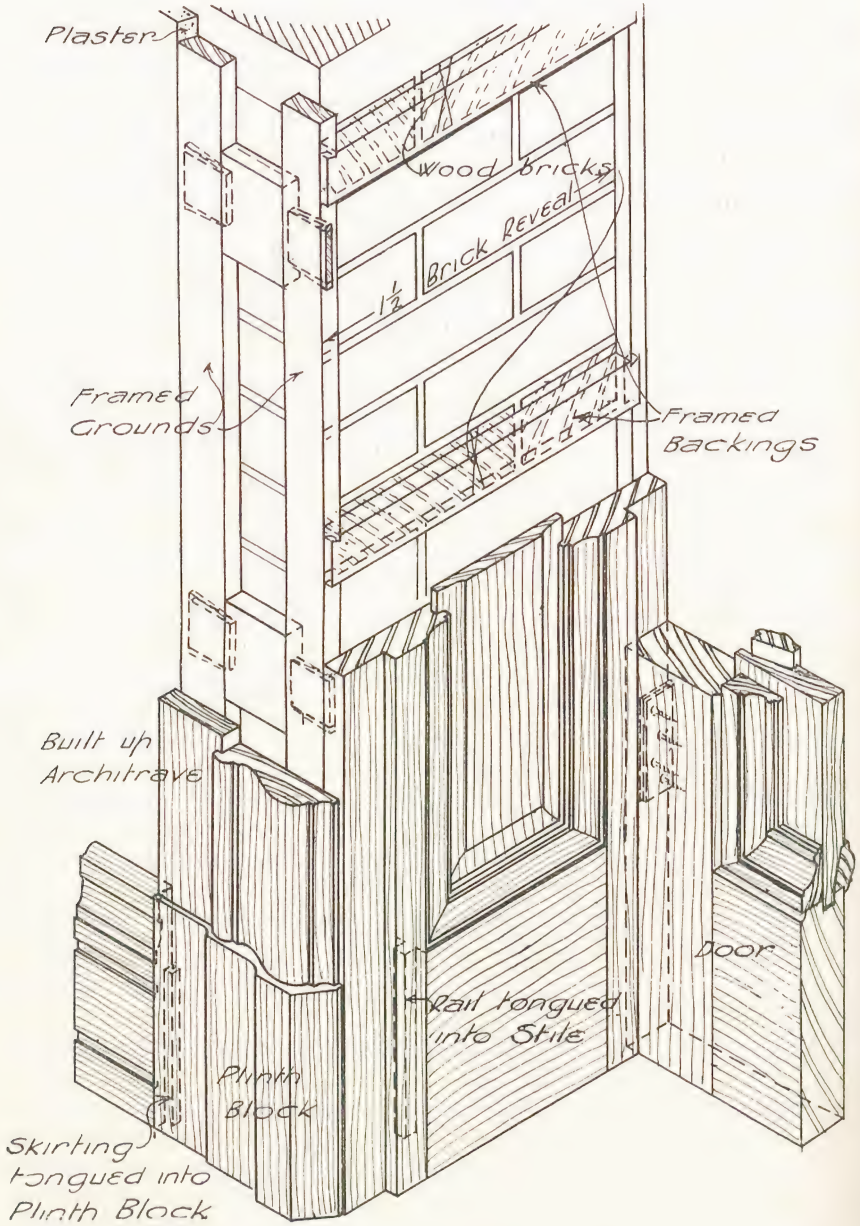


Fig. 1.—A HIGH-CLASS PANELLED LINING

Note that thickness of wall exceeds 9 in. Fixing grounds screwed in position on wood bricks. A " fielded " panel is shown.

Suitable Decorations

Varying finishes can be applied to hardwoods, according to individual taste or the purposes for which the work is required. Oak is often left in its natural state or, like mahogany, teak, and walnut, may be stained to various shades and finished to the grade of polishing desired.

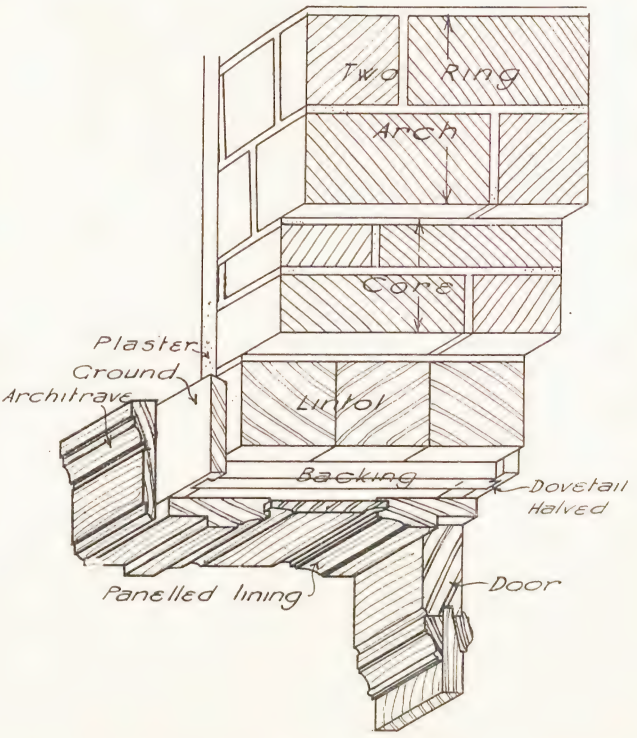


Fig. 2.—PANELLED LINING AT HEAD OF DOOR GROUNDS FIXED TO FIR LINTEL

LININGS

Where Panelled Linings Are Used

Panelled linings are used only when the thickness of the wall through which an opening is made exceeds 9 in., a plain or rebated lining being used in 4½-in. and 9-in. wall thicknesses.

Fixing in Position

In all openings where linings are to be fixed it is necessary to build in suitable blocks, of either wood or coke breeze, to form a rigid base on which the fixing grounds may be secured. The most usual form of fixing blocks are coke breeze bricks, which are made to the dimensions of an ordinary brick and are easily built in and bonded with the brickwork; but where fixing grounds are screwed in position, wooden bricks as shown in Fig. 1 are the more suitable as they give a better thread-hold for screws than coke breeze bricks.

Where door or window openings have fir lintels, these form in themselves suitable fixings, as shown in Fig. 2.

Fixing Strips Embedded in Concrete

In the case of openings having concrete lintels, provision has to be made for fixing strips. These are formed by putting dovetailed pieces of wood

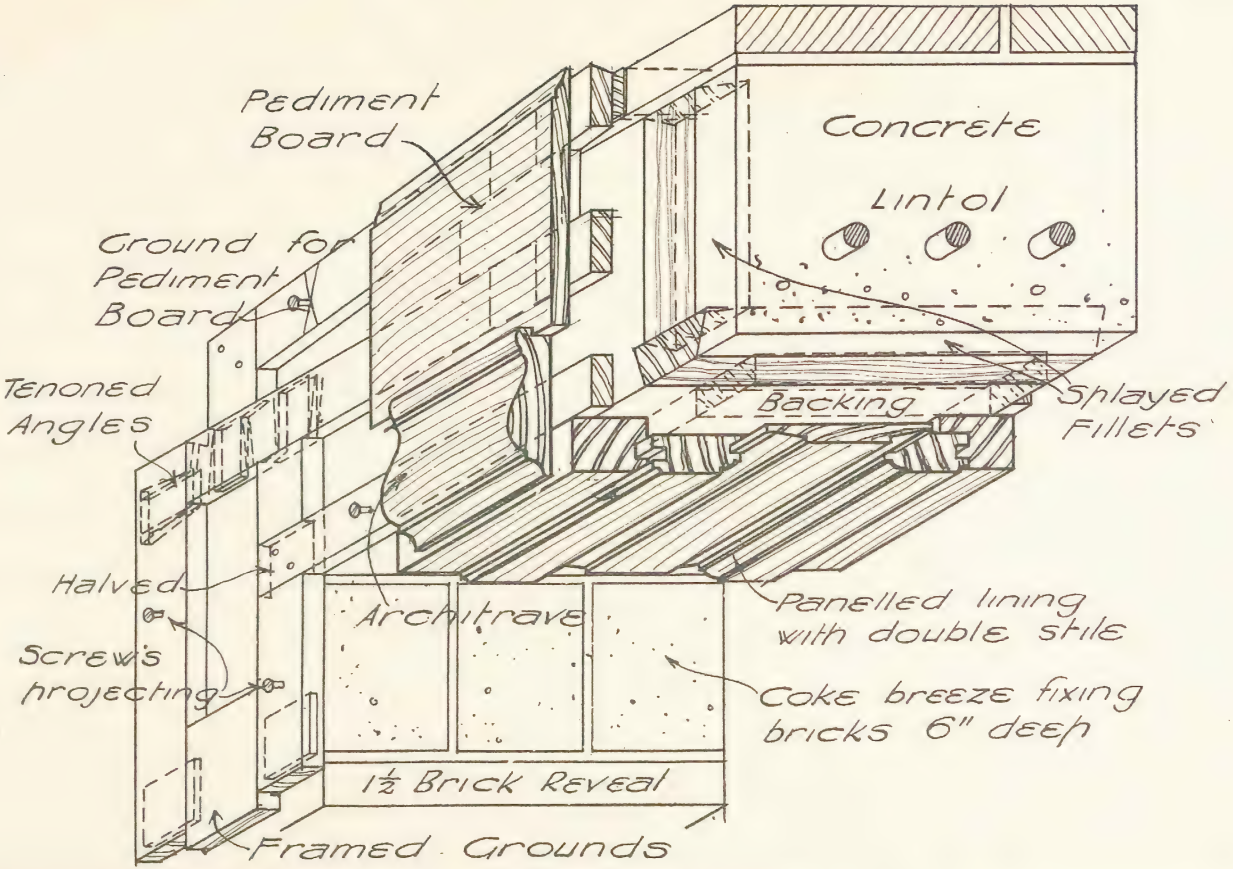


Fig. 3.—FIXING FOR PANELLED LINING AT HEAD OF DOOR

In this case the lintel is of concrete, and the method of fixing the lining to it is shown. Note the use of pediment board. Note the screws for slot and screw fixing, as employed for high-class work.

at the bottom of the shuttered casing in which the concrete lintel is cast. These strips remain embedded in the concrete when the shuttering is removed, and may be placed either at right angles to the length of the lintel, as illustrated in Fig. 3, or run the length of the lintel from jamb to jamb. It must be remembered, however, that an added depth equal to the thickness of these strips is required in order to maintain the effective depth of the concrete lintel, otherwise its strength is reduced. In a similar manner, strips temporarily held in position, if necessary, are cast in concrete wall and ceiling surfaces which are eventually to receive an applied decorative wood treatment.

Why Grounds Are Used

After the provision of fixing blocks and strips, wrought deal grounds are necessary, their primary object being to obtain an even plane on which to secure the panelled linings in the case of doors and windows, or wall panelling in the case of a dado, shown in Fig. 7. These fixing grounds can be packed out as necessary to overcome the irregularities of the wall surfaces due to the inequalities in size and shape of the bricks in the wall.

Careful Adjustment of Grounds Important

Fixing grounds are invariably made of fir and should be wrought both sides, splayed on the appropriate edges to form a key for plaster ; they should receive almost as much care and attention in the framing up and fixing as the panelled surfaces which will eventually cover them, for on the security and accurate adjustment of these grounds largely depends the resultant success or failure in the fixing of the joinery.

Fixing Grounds for Linings and Architraves

The fixing grounds for the linings and architraves of the door opening shown in Figs. 1 and 3 consist of parallel strips secured around the opening, on the surfaces of both sides of the wall in which the opening occurs, braced together with stop dovetailed halved framed backings, and to this combination of grounds the jamb and head linings and architraves are screwed. For narrow architraves, only one ground is necessary on the wall surface around the opening, as shown in Fig. 2.

Margin for Shrinkage

Great care should be continuously exercised to ensure that the grounds are in such positions that they will allow of the panelling, or architraves, etc., covering the joints between wall plaster and grounds by at least $\frac{3}{8}$ in., and this should be sufficient margin to allow for any shrinkage which may occur in the applied woodwork.

The panelled linings illustrated in Figs. 1, 2, and 3 have been carried out in hardwood, the grooved and rebated framing of which has mouldings worked on the solid, the panels being splayed and raised ; this type

Fig. 4.—A GOOD EXAMPLE OF MODERN INTERIOR OAK PANELLING, LININGS, DADO, ETC.

of panel is termed a "fielded" panel.

Where Plinth Blocks Are Used

After the linings have been fixed, the architrave is secured in position, covering not only the joint between the lining and its fixing ground, but also the joint between the wall plaster and architrave fixing grounds, thus forming the frame to the opening. The projection of the architrave from the wall surface should be sufficient to stop the skirting or dado rail, although in first-class work a plinth block is provided as a base for the architraves and a stop for the skirting.

Reference to Fig. 5 shows the shaped housing on the upper surface of the plinth block which receives the architrave moulding, the lower end of the architrave having a shouldered halving and a dovetailed halving which fits into the corresponding sinkings cut at back of the plinth block, which in its turn is housed in a floor sinking. This method is used only in the very best class of work, owing to the amount of skilled labour involved and the consequent expense. The more usual method is simply to shoulder halve

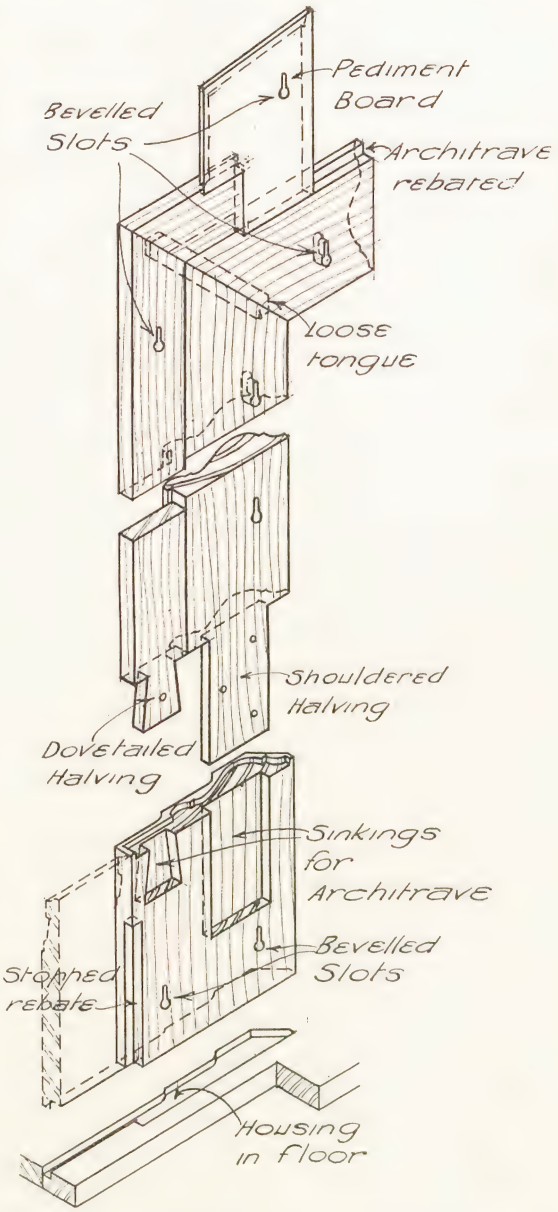


Fig. 5.—JOINT BETWEEN ARCHITRAVE MOULDING AND PLINTH BLOCK

This method of fixing is used only in the very best-class work. Note housing for plinth block in floor. Showing a view from behind.

the bottom end of the architrave to the plinth block on which the architrave moulding stops, without any countersinking in the plinth block.

Where there Is No Plinth Block

It is unusual for even the shoulder halving joint to be made in workmanship of moderate class today, where economy

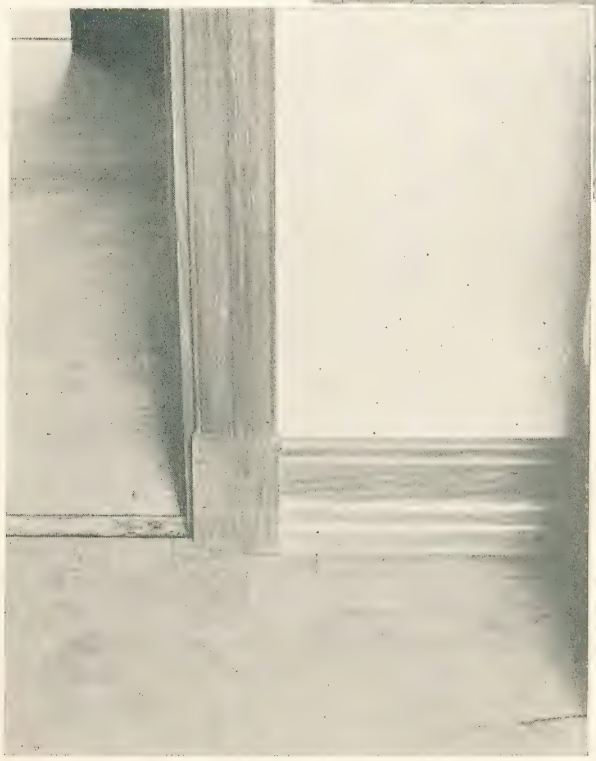


Fig. 6 (*below*). — ARCHITRAVE, BLOCK, AND SKIRTING IN POSITION

Fig. 6A.—ARCHITRAVE WITH BLOCK FOR STOPPING SKIRTING, SHOWING SCRIBING

dictates a sparing use of the highly skilled operative. If both architrave and plinth block are securely fixed to the grounds, a fixing together of the two is indirectly effected; owing to the direction of the grain a shrinkage apart is too unlikely to need consideration. Where no plinth block is used the architrave is carried

down to floor level, and should have sufficient thickness to form the stop for the skirting.

Securing Skirting to Plinth Block

The skirting should be secured to the plinth block, and this is accomplished by forming a tongued and rebated joint as shown in Figs. 1 and 5. Here again this joint would be made only where workmanship of the highest class is desired, a carefully scribed butt joint being ordinarily used nowadays.

Use of Pediment Board

In the case of the door head shown in Fig. 3, a pediment board was introduced into the design in order to give an appropriate architectural emphasis to a portal of some little consequence. The method of securing this in position is shown in Figs. 2 and 3.

Slot and Screw Fixing for High-class Work

In the highest class of workmanship a " slot and screw " method is adopted for securing the decorative woodwork to the grounds. These slots and screws are shown in Figs. 3 and 5. The lining, architrave, or panelling is first of all assembled and placed temporarily in position against the fixing grounds, and convenient positions for fixing points are marked on the grounds ; the assembled joinery is then moved away and screws are driven into the grounds at the places marked, with their heads left projecting from the grounds, this projection being the same as the depth of the slots which are to be cut at the back of the joinery. When all the screws are in, the screw heads are marked with chalk, and the assembled joinery is again placed in position against the screw heads and pressed against them, the chalk on the screws' heads being thus transferred to the back of the woodwork. Bevelled slots are then cut in the back of the assembled joinery downwards for $\frac{1}{2}$ in. from the chalk mark, the width of the slot at the bottoms being increased to a circular hole large enough to admit the screw head. The joinery being ready for fixing is now finally put in position, raised until all the screw heads are engaged in the slots, and carefully lowered.

This method requires the utmost care, but if properly done makes the best possible fixing known. No fixing agents are visible, and the shape of the slots permits a certain amount of movement, should there be a tendency for the woodwork to shrink or swell. The possibility of splitting is thus obviated.

Using Metal Slots

As an alternative to slots cut and shaped in the woodwork, metal slot-plates are sometimes fixed. These are countersunk over sinkings which it is not necessary to shape and bevel, as the metal plates form the holding for the screw heads.

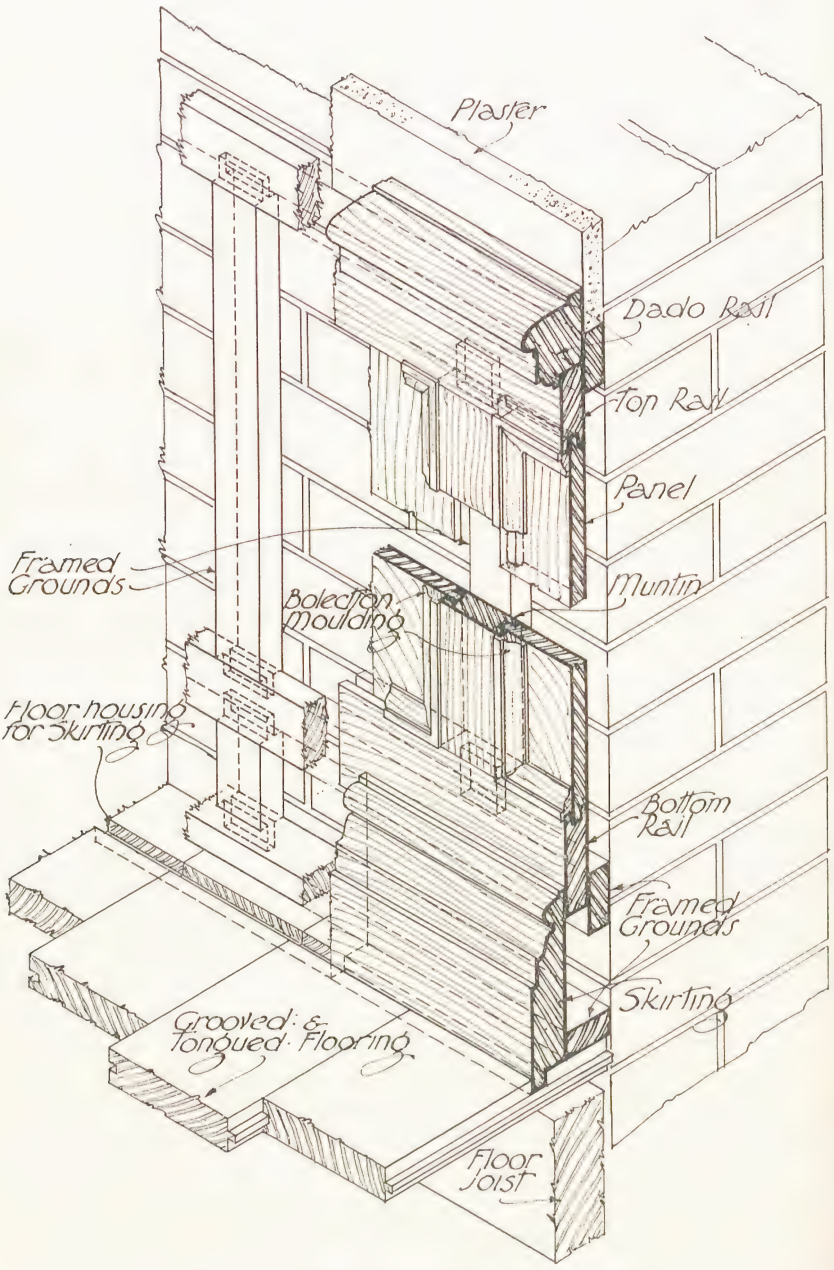


Fig. 7.—A SIMPLE FRAMED AND PANELLED DADO

Showing the various grounds required for fixing. All the grounds are framed together.

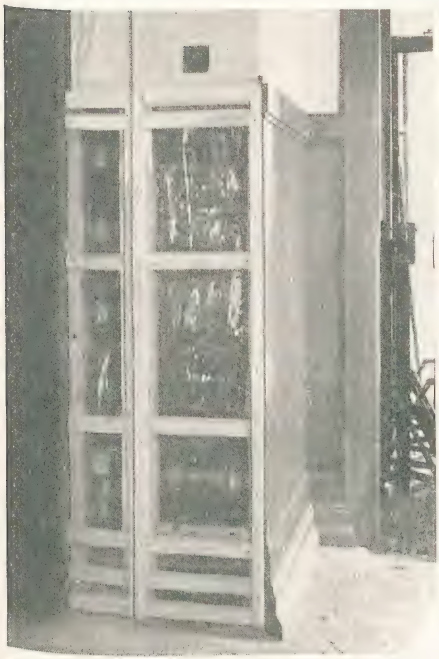


Fig. 8.—FRAMEWORK PREPARED FOR PANELLED DADO

Fig. 8A.—NAILING PANELLING TO FRAMEWORK

Usual Method of Fixing Joinery to Grounds

The usual method adopted is simply to screw or brad the joinery to the grounds, the fixing agents being put in such positions that one or other of the moulded members covers them, or the screw heads are sunk below the surface of the woodwork and the holes "pelleted," which means that small disks slightly wedge-shaped, of similar wood, are lightly driven and glued in the screw holes and finished off flush with the surface. Great care should be exercised to ensure that the grain of the wood pellet corresponds to and runs with that of the adjacent surface, the object being to make the pellet as invisible as possible.

DADOS

Types

The word "dado" is a term used to describe the part of the wall between the skirting and the chair or dado rail, and is usually about 2 ft. 9 in. to 3 ft. in height, but may be higher or lower. It is often treated decoratively by the application of materials differing in texture and colour from those applied to the "filling," that is, the wall area comprised between the dado and frieze. Sometimes durability is a consideration met by the application of a surface constructed of wood in the form of a

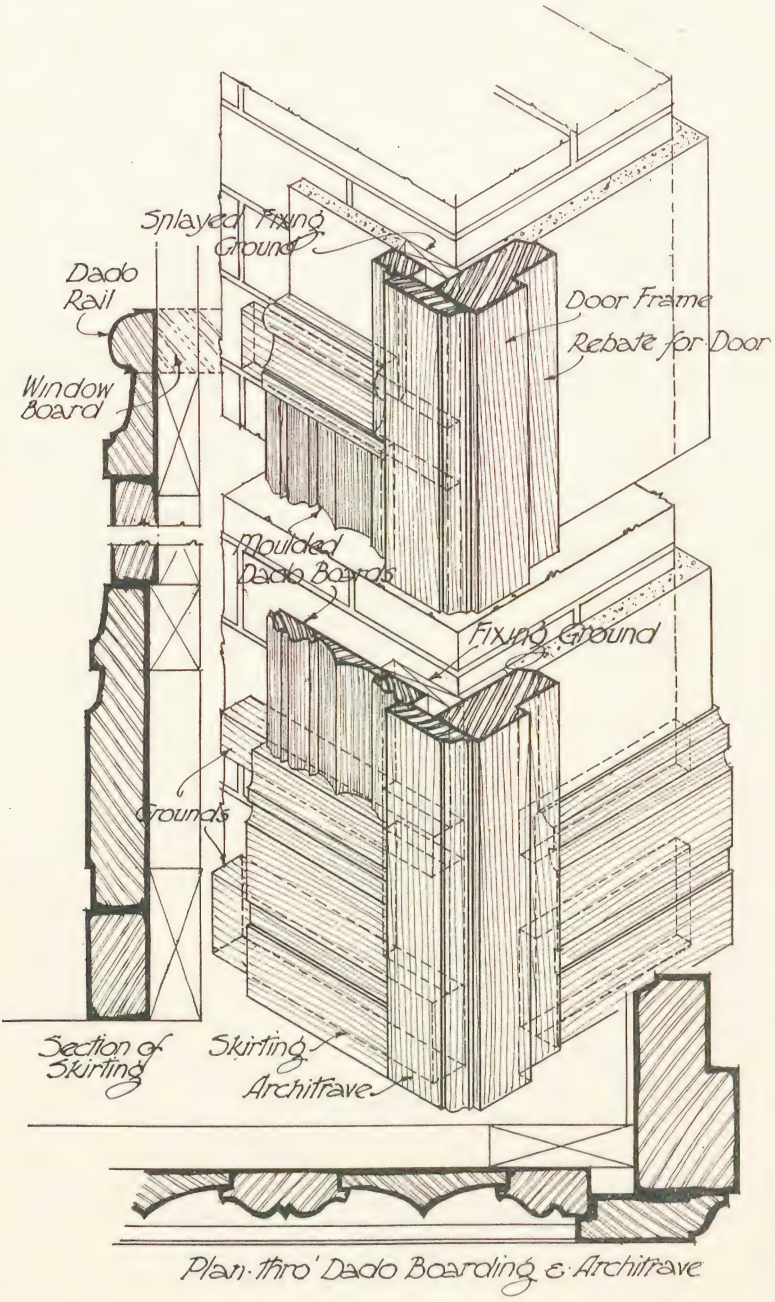


Fig. 9.—USING MOULDED DADO BOARDS BETWEEN DADO RAIL AND SKIRTING

matchboarded dado, moulded boarded dado, or panelling, the latter two of which combine durability with an enriched effect.

What Are Dados For?

The primary use of the chair or dado rail is to prevent the backs of chairs and other furniture from damaging the wall surfaces, and a panelled dado fulfils the double purpose of protecting the lower part of the wall and adding to the decorative effect of an apartment.

Panelled Dados

The panelled dado may be simple in its design or as elaborate as required by circumstances, but the simple one illustrated in Fig 7 is sufficient for the purpose of describing this particular form of decorative treatment.

Method of Fixing

Fixing blocks similar to those described for linings should be built in the walls where panelled dados are required, and to these blocks the fixing grounds are secured. The grounds consist of a skirting ground, bottom rail ground, and a top and dado rail ground, supported at the required height by short vertical grounds between skirting ground and bottom rail grounds, and vertical muntin grounds, between bottom rail ground and top rail and dado ground. These vertical grounds should be arranged to occur behind the muntins, which may be spaced at regular or varying intervals in accordance with the design of the panelling. All these grounds are framed together and secured to fixing blocks.

Panelling for Dado

The panelling shown in Fig. 7 is of simple design, and is formed with $1\frac{1}{4}$-in.-thick top and bottom rails and muntins all tenoned together, each member grooved to receive panels, which are made up of $\frac{3}{4}$-in.-thick boards with rebated edges all round. The joints between the framing and the panels are covered with bolection mouldings, which lie flat on the panels and are rebated to fit over the angles or arrises of the framing and mitred at the corners. The top rail and muntins are usually about 4 in. in visible width, the bottom rail being perhaps 5 in., but these widths vary with the design.

Fixing Framing in Position

After the panelled framing has been assembled it is placed in position on the fixing grounds and screwed to them so that the skirting when fixed will overlap the lower edge of the bottom rail, and so conceal the backings. A chase is cut in the flooring boards to receive the rebated bottom edge of the skirting.

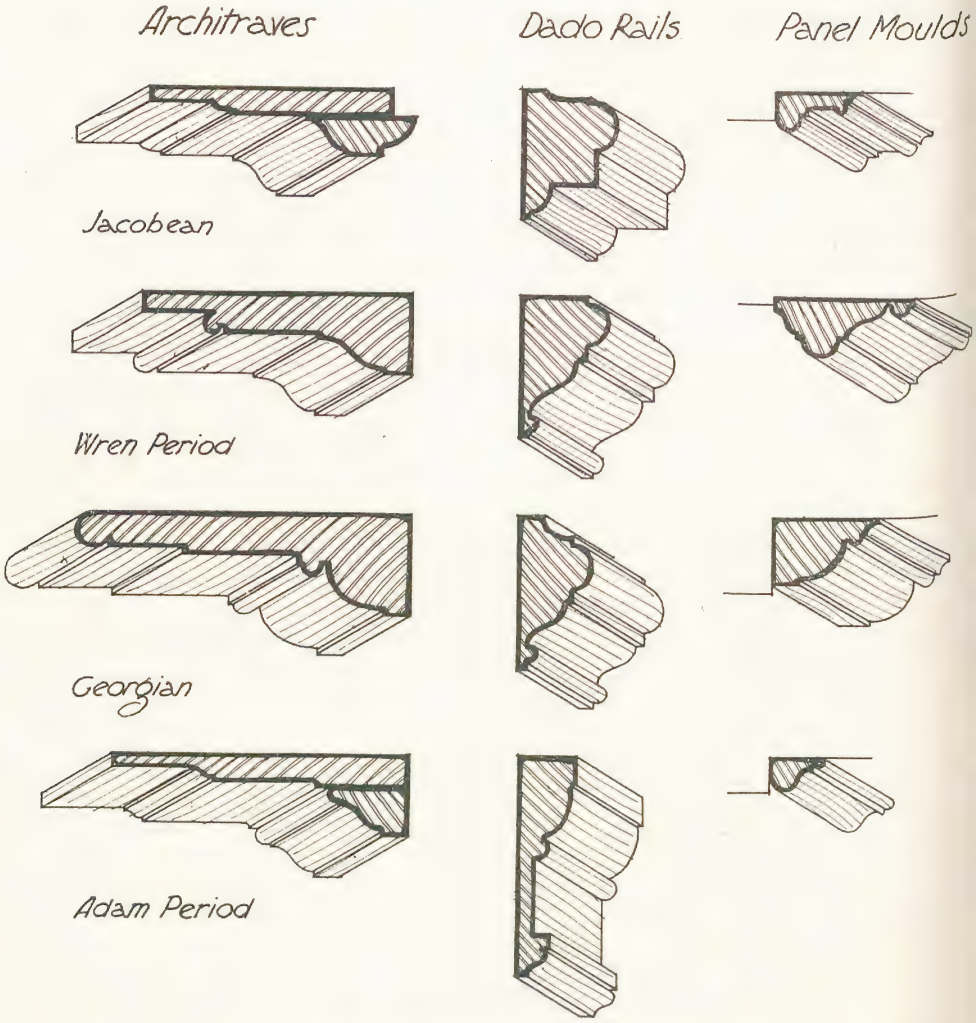


Fig. 10.—TYPICAL " PERIOD " ARCHITRAVES, DADO RAILS, AND PANEL MOULDINGS

Moulded Dado Boards

As an alternative to the framed and panelled dado illustrated in Fig. 7, quite pleasing effects can be obtained by using moulded dado boards placed vertically between the skirting and the dado rail, as shown in Fig. 9. The alternate boards have similarly moulded surfaces, every other board being rebated to cover the joint between it and its neighbour, so that any shrinkage of boards will be masked by the overlapping. The top surface of the skirting must be of sufficient width to stop the mouldings

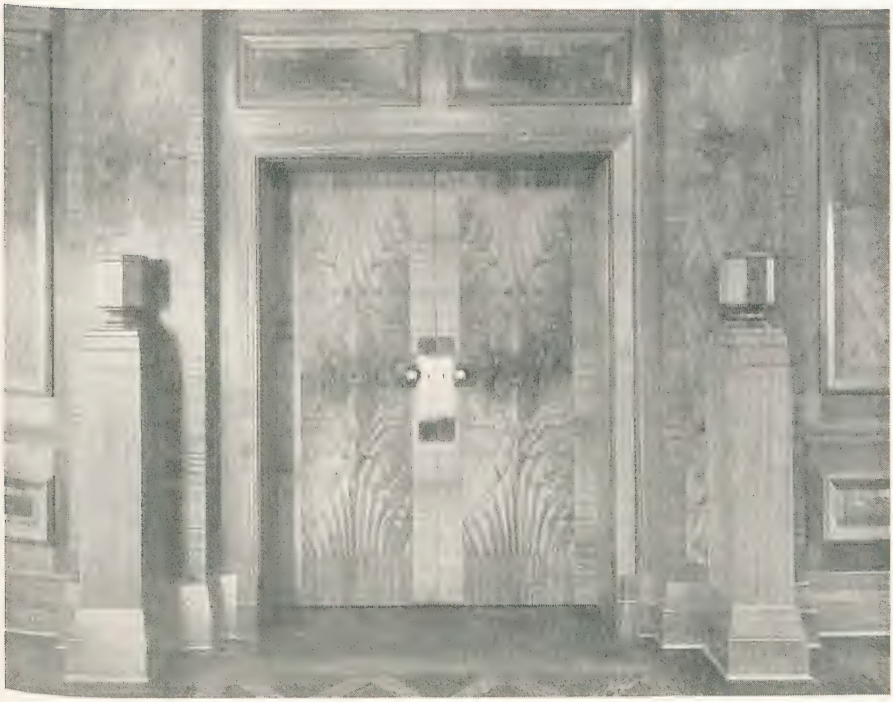


Fig. 11.—DETAIL OF WORK IN AUSTRALIAN MAPLE

The entrance to board room at headquarters of the National Society of Operative Printers and Assistants. (*Architect: E. J. Williams, F.R.I.B.A.*)

of the vertical boards which butt on it, as shown in the large-scale detail plan and section in Fig. 9.

Designed to Give Effect of Repose

It is often possible to arrange the height of window boards to line through with the top of the dado rail, the moulding of the window board edge being similar to that of the dado rail, as shown by dotted lines on the section in Fig. 9; an unvarying dado height is thus maintained continuously around the apartment, giving the added effect of repose.

Use of Ordinary Matchboarding

This type of dado permits of great scope in the design of mouldings generally, and for the vertical boards particularly. Fig. 9 has been prepared from a dado which forms part of a protective wall covering constructed in a club house. The illustration shows that possibilities of the development of ordinary matchboarding, into a decorative treatment, exist and await further exploitation.

Fig. 12.—SOUTH AFRICA HOUSE—HIGH COMMISSIONER'S ROOM
(*Architects : Sir Herbert Baker, R.A., F.R.I.B.A., and A. T. Scott, F.R.I.B.A.*)

Fig. 10 shows typical " period " architraves, dado rails, and panel mouldings.

QUESTIONS AND ANSWERS

When are Panelled Linings employed ?

When the thickness of the wall through which an opening is made exceeds 9 in., a plain or rebated lining being used in $4\frac{1}{2}$-in. to 9-in. thicknesses.

How is provision made for fixing Strips in Concrete Lintels ?

By putting dovetailed pieces of wood at the bottom of the shuttered casing in which the concrete lintel is cast. These strips remain embedded in the concrete when the shuttering is removed. They may be placed at right angles to the length of the lintel or may be run the length of the lintel from jamb to jamb.

Why are Grounds necessary ?

Their primary object is to obtain an even plane on which to secure the panelled linings or wall panelling.

EXTERNAL WALL FINISHES TO CONCRETE-&-STEEL STRUCTURES

PART. I—STONE, GLASS, AND TERRA-COTTA FACE CONSTRUCTION

Fig. 1.—Mittnacht Building, Stuttgart

Walls constructed of concrete and faced with thin slabs of marble. Notice that the jointing of the slabs clearly indicates that they are not used structurally.

MODERN building methods have profoundly modified the function of the external walls. Formerly these were erected for the double purpose of stability and protection; they carried the weight of the floors and roof, tied the structure together, and prevented the penetration of wind and wet.

The use of a concrete-and-steel framing has relieved the walls of

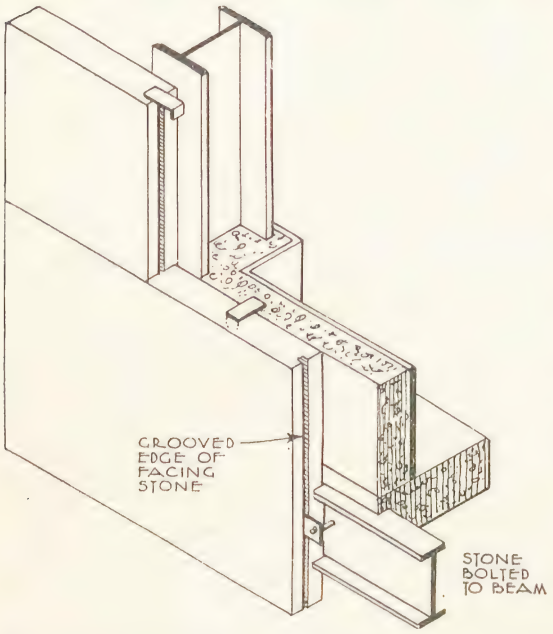


Fig. 1A—OUTER WALLING CARRIED BY BEAMS BETWEEN STANCHIONS

their functions as weight carriers, and left them simply as a means of giving adequate protection from the elements.

Walls Carry Only Their Own Weight

These modern steel structures are usually designed in one of two ways. Either the external walls are constructed so that each carries only its own weight between floor and ceiling, and is steadied at intervals by the vertical support given by the main stanchions, or the stanchions are set back from the external wall face and the floor cantilevered out beyond them, in which case the wall has to be strong enough both to carry itself and to resist wind pressure. But whichever method is adopted, the wall on each floor is entirely independent of that above or below it. There is therefore nothing in modern building practice to prevent the external walls being built from the top floor downwards, an order which is, in point of fact, frequently followed.

Need for Insulation

Since the province of the wall is to provide sufficient insulation against the changes of the external temperature, the choice of materials and finishings has immensely widened. In a solid brick or stone wall the question of insulation scarcely arose, for the thicknesses required for stability were amply sufficient to prevent the passage of heat through them, but now that a wall need be no more than a thin waterproof membrane, strong enough only to support its own weight—such, for example, as a large sheet of plate-glass—this question of insulation becomes a matter of the greatest importance in the selection of a facing material. Glass, for instance, may be the best for light where this is required, as in a large factory, but its use may entail exceptional calls on the heating system ; and a thin metal wall may be sufficient to keep out the weather, but cause endless trouble through condensation due to changes of heat and cold.

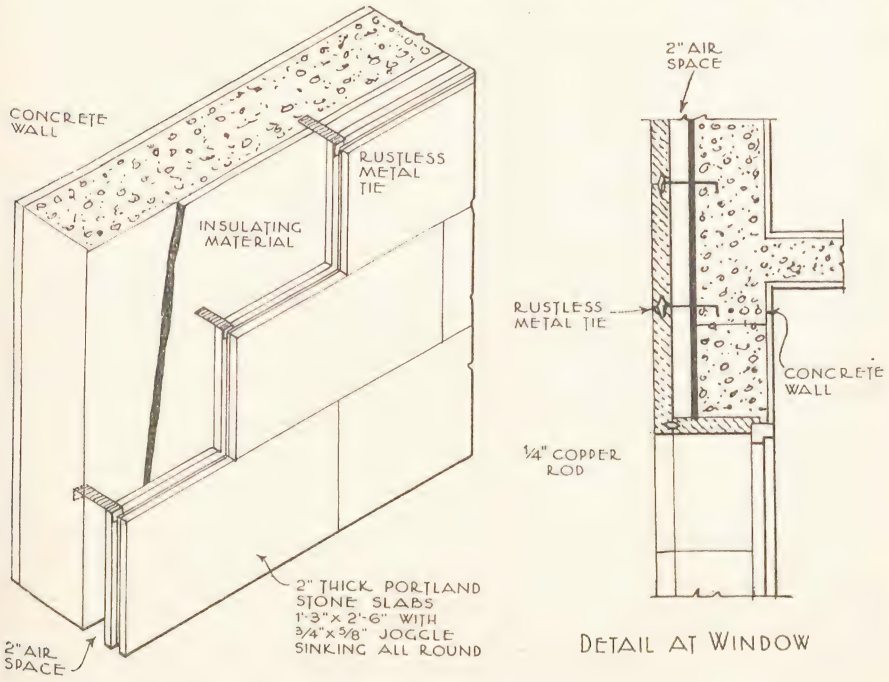


Fig. 2.—ANOTHER METHOD OF CARRYING THIN STONE-SLAB FACING
Air space of about 2 in. between concrete wall and facing.

Materials Used for Facing Concrete Walls

The modern facing materials which can be employed to-day include stone (used as a veneer), precast concrete slabs, terra-cotta, glass, vitrolite, aluminium, cast iron, and combinations of these substances. Also, the monolithic concrete walls themselves can be finished in a number of ways, some of these being produced by the methods employed in forming the shuttering, others by the application of various renderings and face treatments.

STONE FACING

In the past, when facing a brick building with stone, it was necessary to bond the two materials together at intervals with stone bonders, and the average thickness of stone for this type of construction was generally about 7 in. The depth of the stone blocks was governed by the brick courses, each stone being equal in depth to four or five bricks, plus the thickness of the mortar joints.

Thin Stone Slabs

Modern construction still finds stone one of the best of facing materials, but employs it much more economically. A properly constructed

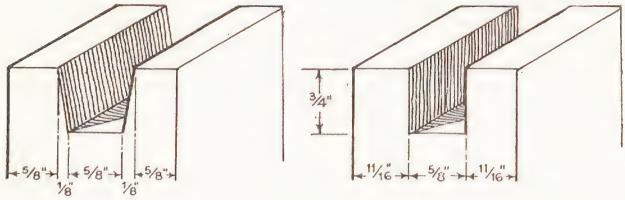


Fig. 3.—DETAIL OF JOGGLES IN 2-IN. STONE SLABS

reinforced-concrete wall, about 5 in. thick, is sufficient to carry itself and allow enough cover for the steel members of the structure. To this wall are fixed slabs of stone about 2 in. in thickness, and of as large dimensions as can conveniently be handled. Sometimes these are placed in contact with the concrete (Fig. 1A), and in this case an insulating material is laid on its inner face; in others the slabs are kept clear of the wall, leaving an air space of about 2 in.; when this method is adopted the insulating material is sometimes placed on the outer face of the concrete (Fig. 2).

Joggled Stones

The edges of the stone slabs are usually grooved all round with a $\frac{5}{8}$-in. by $\frac{3}{4}$-in. joggle (Fig. 3), into which are fixed cramps to secure them to the concrete, the joggles being afterwards filled in with cement. When the top and bottom edges are left smooth the stones can be secured one to the other by means of dowels. The cramps and dowels must be composed of some rustless metal such as bronze, and the former can be of either a channel or H-section. The resulting appearance is comparable to that of an internal wall covered with marble slabs, and the surface can be patterned by arranging the joints in diamond form as well as horizontally and vertically. Colour schemes can also be introduced by mixing different coloured stones, or using travertine or other marbles capable of withstanding exposure to the weather.

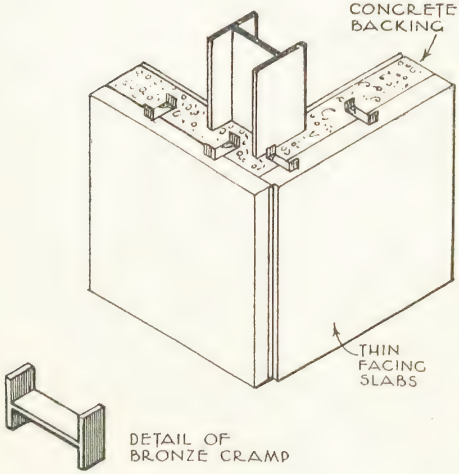


Fig. 4.—ANGLE OF WALL MADE WITH SMALL DOWEL CRAMPS

Joints at Angles

The stones at the angles should be carefully cramped, and lintels over doors and windows should be hung from the steelwork, or otherwise strengthened by horizontal rods. A variation from the plain arris at the corner of a building can be achieved by working a rebate on the stone, and this is sometimes done to give a line, which improves the

apparently weak return of a 2-in. slab when the thickness is exposed (Fig. 4).

Reconstructed Stone Slabs

Reconstructed stone can be cast in blocks having a dovetailed groove at the back (Fig. 5). The slabs are first placed in position, the shuttering built up, and the concrete then poured behind them. The liquid mass is carefully rodded into the dovetailed angles, and bonds the stone and concrete wall together into a homogeneous mass. Walls thus constructed are built up in vertical heights of about 3 ft., which is the usual depth of a "lift" in shuttering for reinforced-concrete work. It is obvious that in this method of building great care must be taken to see that the walls are always plumb.

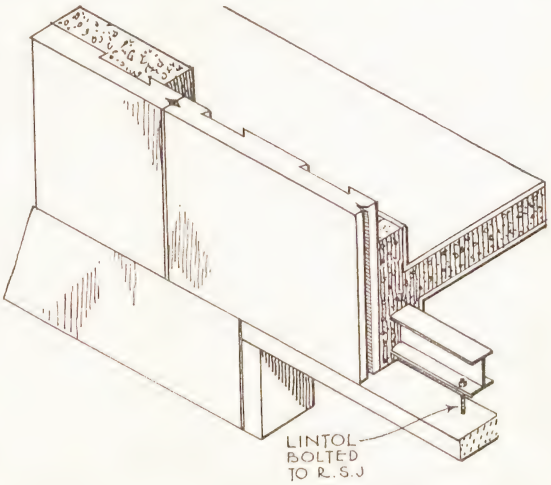


Fig. 5.—ARTIFICIAL STONE SLABS KEYED TO REINFORCED CONCRETE

GLASS FACING

Specially toughened glass has been used for facing concrete walling, and is obtainable in large sheets up to sizes of 70 in. by 54 in.

Armour-plated Glass

If armour-plated glass is employed it should be remembered that this material cannot be cut after plating. Up to the present it is not widely used in the south of England, although several buildings in London have been so faced.

Methods of Fixing

The methods of fixing vary, but whichever is adopted it should be one that allows for easy replacement and gives the panes a certain amount of play to prevent them from cracking through slight settlements or expansion. One way is to punch the wall of the structure and insert lugs at about 2-ft. 6-in. centres, both horizontally and vertically (Fig. 6). These lugs project sufficiently to allow a filling of pumice concrete to be filled in between the main wall and the glass slabs. To the lugs are attached angle irons approximately $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{1}{4}$ in., with flats $1\frac{7}{8}$ in. by $\frac{1}{4}$ in. secured between them projecting beyond a distance equal to the thickness of the glass (about $\frac{5}{16}$ in.) and its bedding. To the front of the flats flat chromium or stainless-steel bars are tapped and screwed

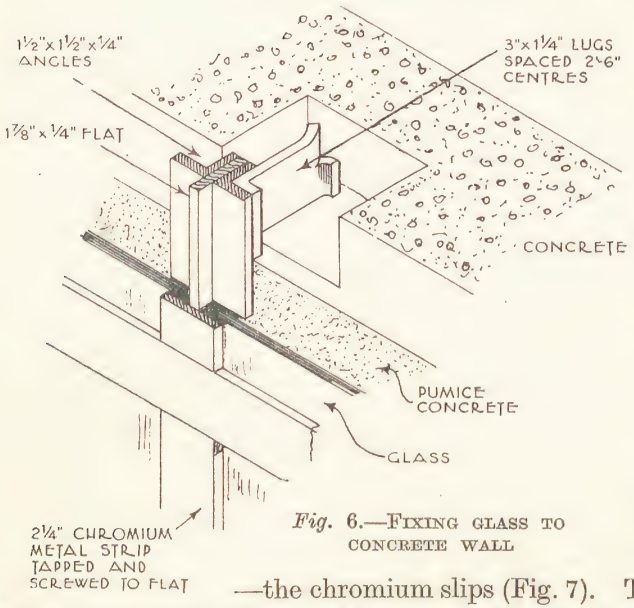


Fig. 6.—FIXING GLASS TO CONCRETE WALL

both horizontally and vertically, to cover the joints. The glass sheets are fitted into the panels so formed, and bedded in lead to give them sufficient play.

Fixing with Teak Slips

Another method consists in bedding teak or hardwood rebated slips in the concrete face, to which are screwed —horizontally only —the chromium slips (Fig. 7). The glass is then fixed between these slips at top and bottom, and bedded with mastic. The space between the back of the glass and the concrete wall is also filled in with mastic, and the vertical joints of the glass panels are puttied in with the same material, coloured or blacked to the tint selected for the glass.

These glass-fronted buildings are easy to keep clean in a polluted atmosphere, and the surface is practically immune from attack by acids in the air.

VITROLITE

Another material, similar to glass, which is becoming increasingly popular for facing external walls, is vitrolite. This is an opaque, hard, non-absorbent material which is impervious to all common acids present in town atmospheres. The back of the sheets is slightly ribbed, and the face has a semi-matt or polished surface. This surface is fire polished, which differs from the ordinary polishing given to plate-glass by being produced during the process of firing. It contains slight irregular-

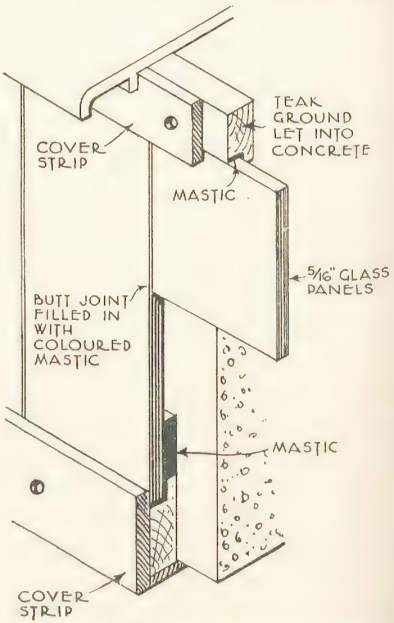


Fig. 7.—ANOTHER METHOD OF FIXING GLASS FACING TO CONCRETE

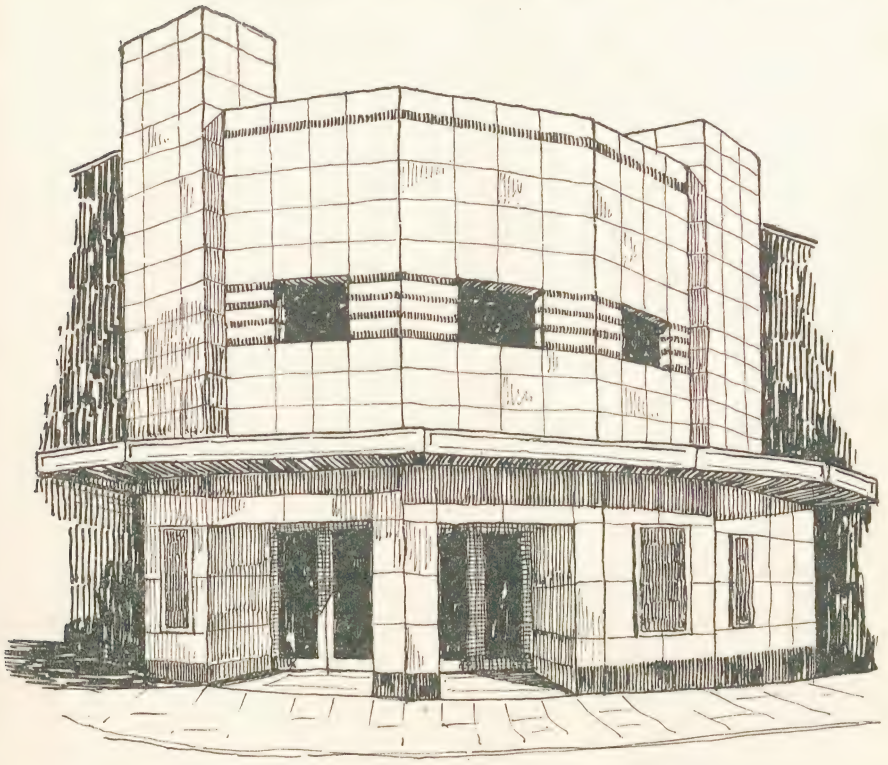


Fig. 8.—A CINEMA FACED WITH COLOURED VITROLITE
There are no cornices, strings, or moulded projections.

ities which when in position on the wall catch and reflect the light, thus avoiding the somewhat monotonous surface produced by a perfectly smooth polishing on opaque glass. A building designed for vitrolite facing should have few breaks on the surface, and avoid all string mouldings and cornices (Fig. 8). Interest must be given by means of differently coloured bands rather than through shadows thrown by projections.

Colours

Vitrolite is obtainable in a number of different colours, all of which are fast and unfading when used externally.

Thickness of Slabs

Slabs are manufactured in the following thicknesses, $\frac{5}{8}$ in. and $\frac{7}{16}$ in. These are sufficient for all vertical wall-surface treatment, but as the material is also used for table and counter tops the black and white shades are also manufactured $\frac{3}{4}$ in., 1 in., and $1\frac{1}{4}$ in. thick.

Weight and Sizes

The weight is approximately that of glass, a square foot of $\frac{5}{16}$-in.-thick vitrolite weighing $4\frac{3}{4}$ lb., and the stock sizes of sheets or panels are :—

12 in. by 8 in.
15 in. by 10 in.
15 in. by 15 in.
18 in. by 12 in.
21 in. by 14 in.

but larger sizes can be obtained if specially required. It should be borne in mind, however, when using this material, that small sheets with frequent joints allow more play and reduce the risk of fracture, and if by chance they are broken are cheaper and easier to replace.

Fixing

When fixing vitrolite sheets a space must be left between the wall and the sheets, which is subsequently filled with mastic or an asphalte compound. As with glass, the chief danger to guard against in buildings faced with this material is the cracking of the sheets due to the unequal expansion of vitrolite and concrete under temperature changes. Fixing can be arranged, as with glass, by means of metal fillets into which the edges are bedded, or applied direct to the wall with mastic only. In the latter case the concrete wall should be smoothed and finished with a Portland cement screed, on to which a special compound is applied with a brush.

Applying the Mastic

The vitrolite sheets are then placed face downward and the serrated backs covered with daubs of mastic about 4 in. or 5 in. apart, and for this purpose about 1 cwt. of mastic will be sufficient for 8 to 10 sq. yd. The sheets are then applied to the wall with a rubbing motion, which spreads the daubs of mastic to an even thickness of about $\frac{1}{4}$ in.

Bed Bottom Course

The bottom course of vitrolite should always be bedded on some soft material, such as felt or leather, or a specially provided bituminous expansion tape about the same width as the sheets. This expansion tape should also be inserted between all horizontal joints, and laid so that the edge is kept back very slightly from the face.

Vitrolite Can Be Cut

Vitrolite can be cut and drilled and have the edges ground true for butt jointing, and may thus be fixed in another manner from those already described. This is to provide a wood backing (plugged to the concrete) composed of teak or other hardwood, and to screw the sheets to this framing.

Screwing Vitrolite to Wood Backing

Care must be taken not to screw too tightly, and to see that the face is absolutely true, or the sheets will crack. When fixing, all screws should be passed through bushes cut from lengths of small brass tubing, and should have soft washers placed between the vitrolite and the wood backing.

Bearing Brackets

If there is any chance of the weight of the upper sheets bearing on the lower—should they do so the edges will scale—small brackets should be fixed to the concrete. These are L-shaped supports which, through bearing the lower edges of the vitrolite sheets at intervals, transfer the weight to the wall behind.

Pointing

Care must be exercised to make all joints watertight, and to prevent the weather from getting behind the panels to the mastic coat. On completion of the work all the joints must be carefully pointed with a pointing compound composed of white lead and varnish; this may be coloured to the shade of the vitrolite slabs with which it is used.

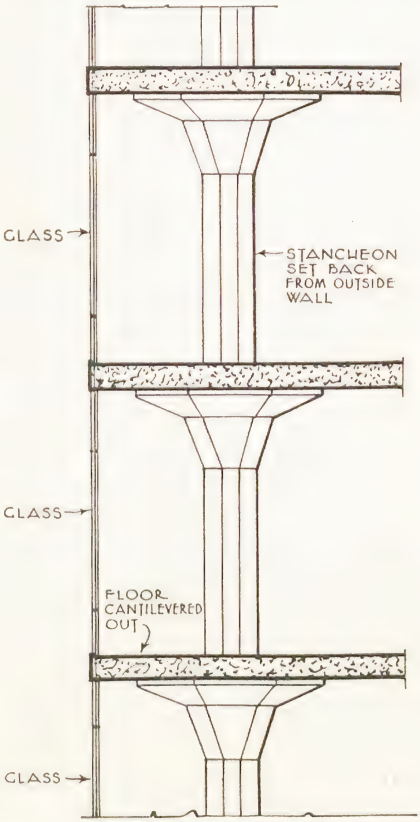


Fig. 9.—SECTION SHOWING ALL-GLASS EXTERNAL WALLS AND REINFORCED CONSTRUCTION

ALL-GLASS FRONTS

The all-glass front is really an extension of the metal window (Fig. 9), and provided the vertical and horizontal bars are strong enough to resist wind pressure is a sound type of walling where the maximum amount of light is required. One of the largest examples of this type of structure in the country is Messrs. Boots' Factory at Beeston, in Nottinghamshire, (see page 49, Vol. I) but all-glass fronts are common in other countries of Europe, notably Germany (Fig. 10) and Holland.

Radiation from Glass Walls

Such buildings are noisy, as the glass walls do not absorb sound, and the radiation of heat through the glass is considerable, necessitating either

Fig. 10.—BREUNINGER STORE, STUTTGART

The wall facings are entirely composed of glass and travertine marble slabs, fixed to continuous horizontal beams.

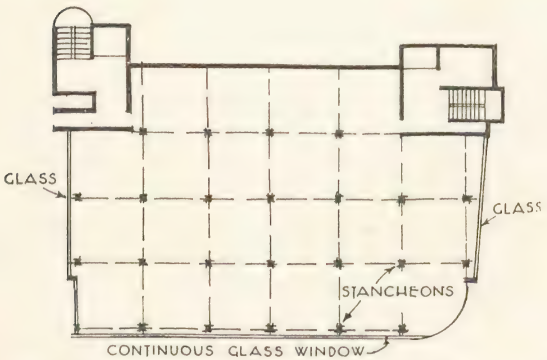


Fig. 10A.—PLAN OF BREUNINGER STORE, STUTTGART, SHOWING WALLS INDEPENDENT OF SUPPORTS

double glazing or extra cost in running the heating systems.

TERRA-COTTA AND FAIENCE

Terra-cotta clays are found in many parts of England, some of the best-known being mainly fire-clays dug in the districts round Tamworth and Leeds. These clays when burnt produce a buff terra-cotta block, which may, however, be tinted by mixing red marl or other colouring material with the clays.

Terra-cotta Blocks

Well-burnt terra-cotta blocks or slabs should be free from cracks, possess a surface with true shapes, and be free from chipping at the edges. As terra-cotta shrinks considerably in baking, small blocks about 1 ft. cube will give the best results. When terra-cotta is used to face brickwork, the sizes of the blocks must bear some relation to the brick courses with which they have to bond, but for use with reinforced concrete

walling this restriction does not apply, and the sizes of the blocks may be arranged in the most convenient manner for the work.

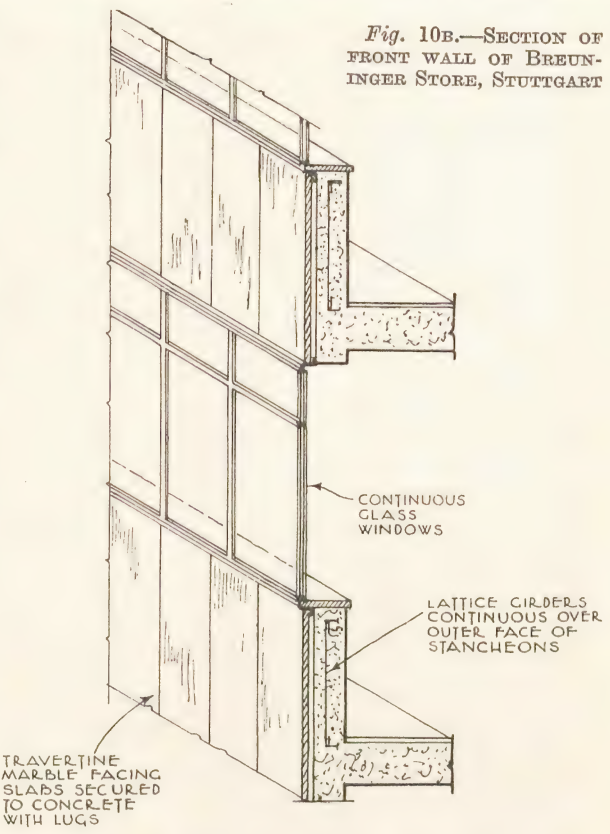


Fig. 10B.—SECTION OF FRONT WALL OF BREUNINGER STORE, STUTTGART

Sizes

Terra-cotta walling is made either in slabs or in hollow blocks. The latter are open at the back, and sometimes have a diaphragm across the middle to prevent the warping of the larger blocks. When laying, care should be taken to see that the hollow space is entirely packed with concrete, and in a reinforced-concrete wall the concrete should be run in to the back of the blocks to form a monolithic wall (Fig. 11A). By careful arrangement of the shuttering, considerable saving can be effected by using terra-cotta as a facing material.

All modern terra-cotta is glazed in the manner of faience. These glazes are opaque and of a dull white, ivory, or brown shade, and are applied as a liquid or spray to the block before firing; when withdrawn from the kiln they present a much harder surface than that usually applied to interior majolica works.

Terra-cotta Panels

Terra-cotta can also be had in slabs or panels of various stock sizes, from 24 in. by 12 in. to 12 in. by 9 in. These slabs are glazed on the face only, and are in the nature of a faience, having a ribbed back to form a key with the wall rendering (Fig. 12). One difficulty with slab terra-cotta facing has been the finish at the angle, as the exposed 1-in. thickness of the return edge is not glazed. This has been overcome by special L-shaped angle slabs having a return face of from 2 in. to 2½ in., glazed in a similar manner to the face (Fig. 13).

By courtesy of the Leeds Fireclay Co.

Fig. 11.—BUILDING FACED WITH TERRA-COTTA SLABS ON CONCRETE BACKING

Notice also the construction with stanchions set back from front, this allowing a continuous expanse of glass window on all floors.

Fixing Terra-cotta Slabs

As already stated, terra-cotta blocks are best fixed while the reinforced-concrete wall is being built, but the facing slabs, which are in

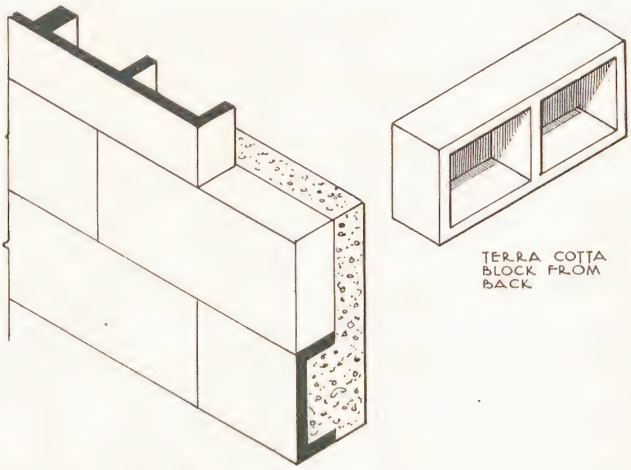


Fig. 11A.—CONCRETE WALL BUILT WITH A TERRA-COTTA BLOCK FACE

many ways a better method of sheeting concrete walls, are applied by means of a cement and sand rendering. The backs of the slabs, which for the best work should not be larger than 24 in. by 12 in., are coated with cement mortar and pressed against the concrete face until the backing is about 1 in. thick. The mortar should be tamped down once the slab is in a vertical position, to ensure that no air holes are formed behind it, and sometimes a little water or thin grout is poured in to ensure a solid backing. Although these slabs will adhere quite satisfactorily to a surface with a proper key, an extra precaution is sometimes added by means of copper cramps which are hooked into a groove prepared in the edges of the terra-cotta slab (Fig. 16). When using these cramps it is a good practice to cast special metal pockets at regular intervals in the reinforced-concrete walling as it is built up in the shuttering, and to cement the ragged end of the cramp into these pockets as they are placed in position during the erection of the terra-cotta facing. The best results are obtained by close collaboration between the architect and the terra-cotta manufacturers in the early stages of the design of any building to be faced with this material, and where possible the placing of the slabs at the same time as the shuttering and pouring in the wet mixture will make the most satisfactory job, and avoid any necessity of using the copper cramps.

Jointing

The joints between slabs or blocks should be about $\frac{1}{4}$ in. thick, and finished with pointing stuck and weathered. During erection care must be taken to keep the vitrified face free from cement stains and mortar droppings, and on no account should any block or sheet be accepted for the work, of which the facing glaze has become chipped or cracked.

Fireproofing Steelwork

Where terra-cotta slabs are built round steel stanchions for the purpose of protecting them from fire, the space between the blocks and steel should

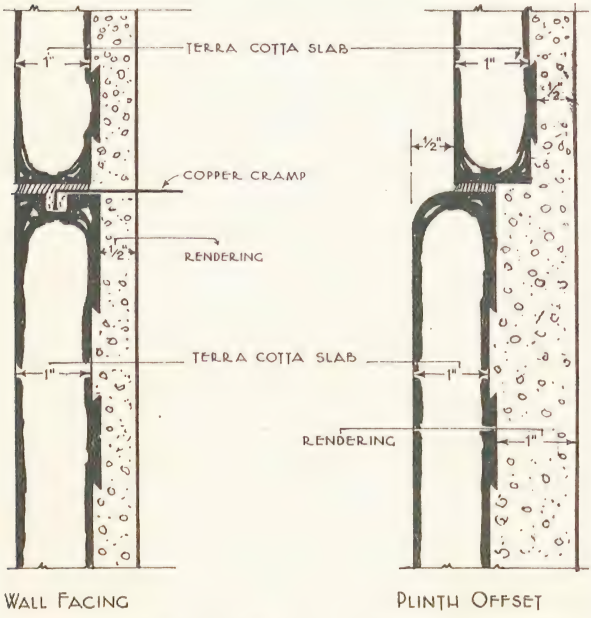


Fig. 12.—TERRA COTTA-SLAB FACING ON CONCRETE

not be filled in with concrete as in external wall construction, the air space acting as a non-conductor of heat.

Specially Made Blocks

In designing a large building to be faced in terra-cotta it is usual to prepare a detail drawing of the elevations, showing the shapes and sizes of all the blocks, and the manufacturer will make his own corrected shrinkage drawings from these details. Some of these, especially where they have to be fitted round stanchions or beams, will have to be made purposely, but such specially shaped blocks will not entail extra expense on a large building, provided that they are standardised.

Ornament in Terra-cotta

If ornamental work is to be included it should be in the form of running bands and repeated patterns which can be cast from one or two moulds. Practically any form of architectural ornament can be produced in terra-cotta, and one need only remember a building like the Certosa at Pavia to realise how varied these can be. But in modern work it is uneconomical to make single castings such as a Corinthian capital or a piece of Gothic tracery, as such items will probably cost more if executed in terra-cotta than if cut in stone.

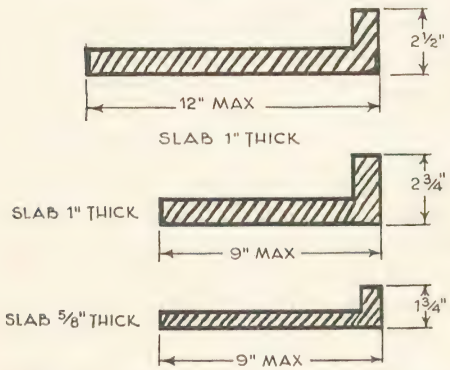


Fig. 13.—TERRA-COTTA EXTERNAL ANGLE SLABS

Most terra-cotta firms, however, carry a large stock of models, and can supply from stock suitable small ornamental features without going to the cost of preparing special patterns.

Fig. 14.—LIVERPOOL GAS CO. OFFICES AND SHOWROOMS

The whole of the external elevation to Bold Street is veneered with golden quartzite and Swedish green marble. (*Architects : Quiggin & Gee, FF.R.I.B.A.*)

Other Materials for Facings

Other facing materials are dealt with in Part II of this section. These include methods of building with different mixtures of concrete, which largely depend for their effect upon the colour of the concrete and the aggregate. As it would be expensive to make the wall of these special

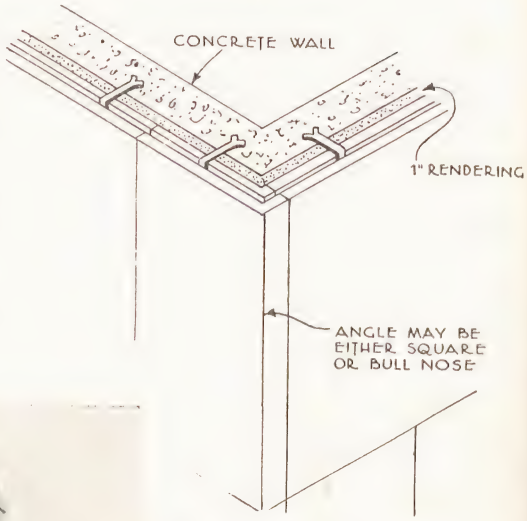


Fig. 16.—TERRA-COTTA SLABS SECURED AT ANGLE WITH COPPER CRAMPS

Fig. 15.—"EVENING GAZETTE" BUILDING AT BLACKPOOL

The building is faced in terra-cotta. (*Architect : Halstead Best, F.R.I.B.A.*)

materials to its full thickness, the wall is built in two different materials at the same time—the facing mixture and the ordinary concrete. The methods employed for this are dealt with in the next part of this article.

The method of construction using precast concrete slabs and the methods employed for forming finished surfaces to concrete walls by means of the shuttering are also dealt with later. Concrete surfaces can also be painted and stained.

Aluminium covering construction is also another possibility. It has been extensively used for the external facing of buildings in America, in some cases entirely replacing other forms of wall construction.

EXTERNAL WALL FINISHES TO CONCRETE-&-STEEL STRUCTURES

PART II.—BUILDING WITH DIFFERENT MIXTURES OF CONCRETE—ALUMINIUM COVERING—CAST-IRON COVERING

Fig. 1.—Dorchester Hotel, Park Lane, London

The front is entirely faced with precast concrete slabs built in as the main walls were cast in the shuttering. The facing slabs are composed of No. 2 Snowcrete mixed with crushed Botticino marble.

THE methods of finishing concrete walls by building with different mixtures of concrete depend largely for their effect upon the colour of the concrete and the aggregate, and to make the wall of these special materials for its full thickness would be expensive. Concrete walls can now be built in two different materials at the same time in the following manner. The two different mixes are separated by means of a steel shutter, from 4 to 6 ft. long, about 2 ft. deep and $\frac{1}{8}$ in. thick, which is placed from $1\frac{1}{2}$ in. to 2 in. away from the outer shuttering. The facing mixture is first put into the narrow compartment, and the

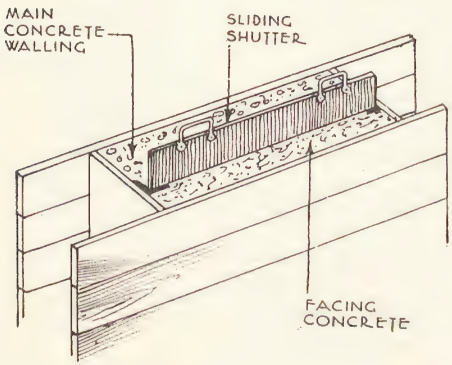


Fig. 2.—BUILDING WITH DIFFERENT MIXES OF CONCRETE

The two different mixes are separated by means of a steel shutter.

ordinary concrete filled in behind (Fig. 2). The two tips of concrete are then thoroughly consolidated and the steel shutter drawn out, thus allowing them to bond together. A simpler method is to divide the two mixes by means of expanded metal or wire mesh, which remains permanently in the structure, the two concretes amalgamating through the meshes.

Precast Concrete Slabs

Concrete facing is also done by means of precast slabs, which are cast in moulds and generally have a grooved sinking all round the edge, with reinforcing bars left projecting at the back to assist in bonding.

The slabs can be cast in a variety of colours by using special aggregates, and either white or natural Portland cements. The Dorchester Hotel in Park Lane, London, is an example of this method of building (Figs. 1 and 3). Here the slabs were made up with a mixture of Botticino marble chippings and cream-coloured cement.

The method of construction was to use the precast slabs as the outer face of the shuttering, a 2-in.-thick layer of cork was employed for the inner, and the reinforced concrete wall was joined in between them. The Dorchester Hotel slabs were about 2 ft. long, 1 ft. high, and 2 in. thick, and the face was polished to a surface similar to a fine terrazzo floor.

Finished Surfaces Formed by Shuttering

A number of different finishes can be given to concrete walls by arranging the timber of the shuttering so as to give different impressions on the mixture when set. Nearly all types of planking will leave a mark on the face of a poured reinforced-concrete wall when removed, although in close-grained hardwoods the impression of the grain is almost invisible.

Grooved and Tongued Boards

The use of narrow grooved and tongued boards in the sides of the shuttering will leave a definite impression of lines on the face of the concrete wall ; by using boards over 6 in. in width these lines can be emphasised into ridges, as the wider planks will curve when in contact with the wet concrete mass. This is a very effective finish for the lower storeys of a building, where the large boards, marking strong horizontal lines, give scale. To obtain even more pronounced horizontal lines on

the concrete, square-edged boards should be used in place of tongued and grooved (Fig. 4).

Oiled Planks

The grain of the planks can be prevented from rising and marking the concrete by coating the inside of the prepared formwork with oil, and a much more uniform surface can be obtained by using oiled instead of unoiled planking.

If the shuttering is composed of chamfered boards, a V-shaped projection is formed between each on the face of the concrete. Boards bevelled $\frac{1}{16}$ in. deep and $\frac{1}{4}$ in. wide will give a projection $\frac{1}{2}$ in. in width, which is very effective when employed with 4-in. or wider planking. By increasing the width of the chamfer a very pronounced moulding will result, which from a distance will have the appearance of a rustication (Fig. 5).

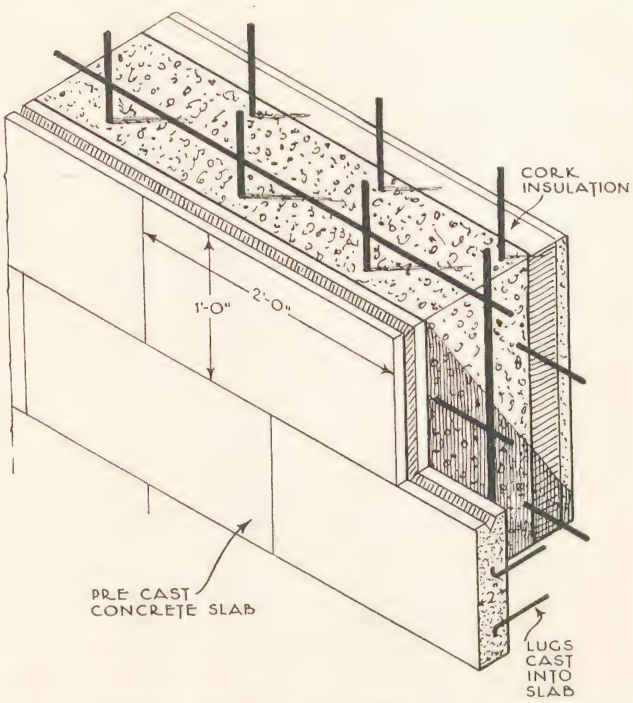


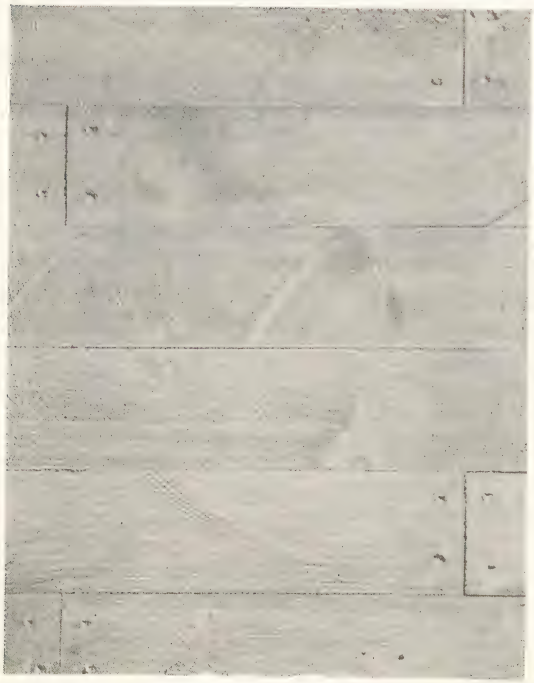
Fig. 3.—FACINGS OF PRECAST CONCRETE SLAB AT THE DORCHESTER HOTEL

Weather-board Shuttering

Sometimes the outer face of the shuttering is laid with overlapping weather-boards, but as the result is only to give the concrete surface the appearance of a petrified wooden wall when the shuttering is removed, there is little to recommend this practice.

Plywood and Canvas

Plywood and canvas are sometimes used to give special finishes. The former produces a dead smooth face broken into large panels by the slight projection of the concrete at the joints. The latter reproduces the grain of the canvas and masks all joints.



By courtesy of the Cement & Concrete Assn.

Fig. 4.—FACE OF CONCRETE AFTER THE REMOVAL OF SHUTTERING MADE OF 4-IN. SQUARE-EDGED BOARDS PLANED ON ALL SIDES

Crêpe Rubber

Crêpe rubber has also been used for lining the inside of the shuttering. It is a material that can be used over and over again, and will give a broken surface to the concrete wall either as a texture to be left exposed, or as a key for holding plaster.

Exposed Aggregate

Another finish is to expose the aggregate with which the wall is compounded by removing the skin of cement which forms against the shuttering. This may be done in several ways.

Retarders

One of these methods is to paint the shuttering which comes in contact with the concrete surface with a special cement retarder. These can be bought either in liquid form or in jellies, and their property is to act upon the surface skin and prevent it from setting, so that when the shuttering is removed at the end of about a fortnight this unset cement can be brushed off, leaving the aggregate exposed.

Bush Hammering

Another method, which may be carried out either by machine or by hand, is known as bush hammering. This is a process somewhat similar to scrubbing, as it cuts away the hard mortar and leaves the aggregate, but care must be taken in its use, for unless the wall has thoroughly set the small particles of aggregate will be knocked away with the cement. For this reason it is dangerous to bush hammer near angles or sharp mitres, and where these occur the work should be hand tooled, as the edges may spall.

Sand Blasting

Sand blasting can also be employed on a concrete wall to expose the aggregate. The usual method is to force a stream of sand through a

compressed-air machine, and by means of a nozzle direct it against the concrete surface, when the skin will come away with the sand. Workmen employed in this process should be properly protected by means of respirators from inhaling the minute silicon particles, and on the whole the method is one better employed in the workshop on precast work, than on the wall of a building in course of construction.

By courtesy of the Cement & Concrete Assn.

Fig. 5.—ROUGH-SAWN TIMBER IN SHUTTERING BEVELLED TO GIVE A PROJECTION BETWEEN EACH PLANK WIDTH WHEN BOARDING IS REMOVED

Rubbing

Rubbing produces a fine, smooth finish, and the success of this method depends upon carefully judging the right time for carrying it out. The cement and aggregate should have reached approximately equal hardness, or one will be rubbed away before the other ; and tests should be made on small samples before beginning work on the main wall.

Carborundum is usually employed to rub down concrete, but York or Mansfield stone is also suitable. The work is usually carried out by the use of electric surfacing machines, and undertaken by skilled workmen. Concrete will also take a polish if the rubbing is continued, by substituting a fine for a coarse disk on the machine, or using snakestone in the parts where a machine cannot be employed.

Tooling

Precast concrete slabs can also be tooled in the manner of ordinary stone, with a mason's boaster and wide chisel having a serrated edge. It is best to employ this method of finishing the angles of all concrete work, as the mechanical means employed to expose aggregates will probably spall off the material at corners, leaving an unpleasant ragged arris to the building.

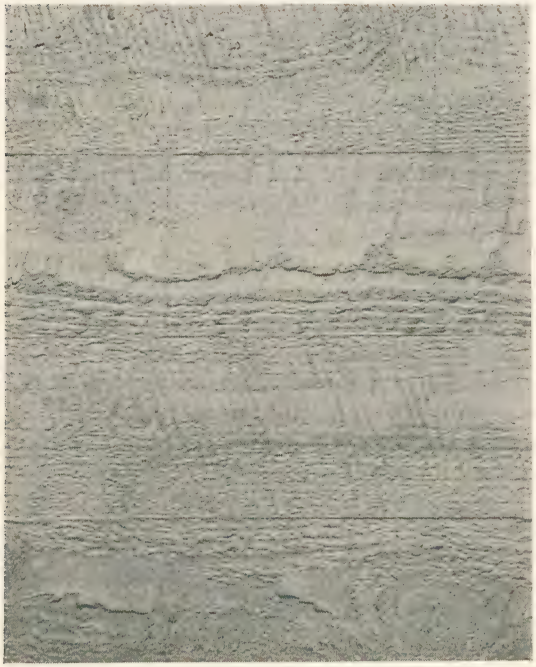
Cement Renderings

One method of finishing the external walls of a concrete building is to treat the concrete itself with a pleasant-coloured wash or slurry, made

up of Portland cement, sand, and water. Naturally the shade will vary according to the mix. Ordinary Portland cement when dry has a greyish and rather drab appearance, but a bright finish can be obtained by employing a white cement. The colour can also be varied by mixing the cement with various shades of sand, so that nearly all tones can be produced from snow white to dark brown without the addition of colouring pigments. But for external work it is best to restrict the colours to cream or white, as darker tints are liable to be disfigured by efflorescence.

Cement Wash

The slurry should first be mixed dry, and then have water added until the mixture is of the consistency of stiff paint. The addition of about 5 per cent. of hydrated lime is sometimes advantageous, as it tends to reduce the harshness of the mix. Only enough of the slurry should be made to last an hour ; the pail should then be cleaned out and a fresh batch prepared. During the application of the slurry to the wall it should be frequently stirred. Provided that the sand is bone dry there is no harm in making up sufficient of the mixture, dry, to last the day's work ; but any dampness in the sand will cause the dry mixture to begin to set, and thus lose its virtue before use.



By courtesy of the Cement & Concrete Assn.

Fig. 6.—FACE OF CONCRETE AFTER THE REMOVAL OF ROUGH-SAWN BOARDS 6 IN. DEEP

The vertical joints are made afterwards. This finish is also a suitable base for "spatter dash."

Method of Use

Before applying the slurry to the face of the wall the cement should first be well wetted, and the mixture then laid on with a full brush. On completion the surface should again be brushed over with water, so as to render the skin as thin as possible, provided that the concrete is everywhere covered.

Rubbing with Carborundum

Rubbing with a carborundum brick improves the surface and makes a better bond by forcing the wash

Fig. 6A.—DE LA WARR PAVILION, BEXHILL. VIEW OF RESTAURANT WING, WITH LIBRARY OVER

The whole building is constructed on a welded steel frame. The external walls are of double thickness of reinforced concrete with a ventilated air space between. The building is rendered externally in a special non-crazing cement, with vertical dark brown expansion joints dividing it up into regular panels, of cream colour, to avoid irregular cracking likely to occur in walls of such large areas. It is finished with white stone coping, brown steel windows and balustrades. The terrace, balconies, and roof garden are paved in brown tiling. (*Architects : Erich Mendelsohn & Serge Chermayeff, F.R.I.B.A.*)

Fig. 6B.—DE LA WARR PAVILION, BEXHILL

South stair, with theatre on left, restaurant on right, seen from flower box. An example of concrete wall finished with cement rendering.

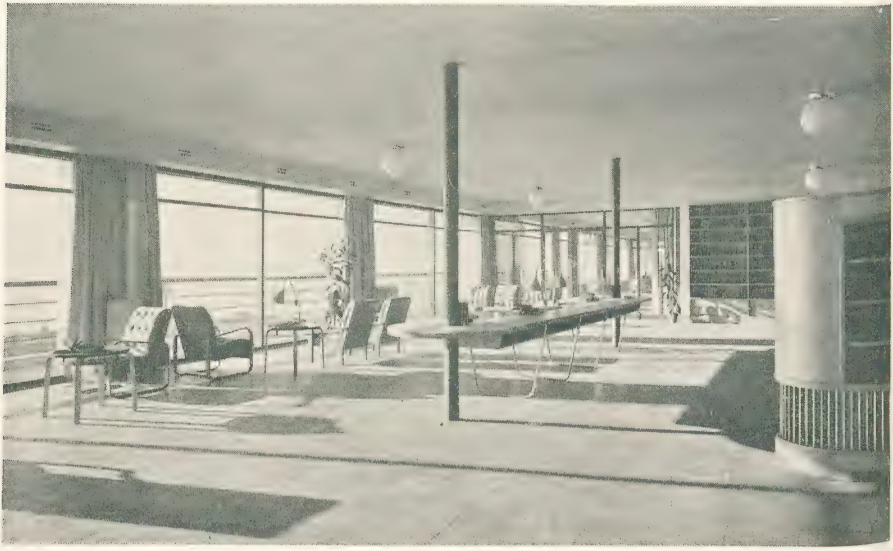


Fig. 6C.—DE LA WARR PAVILION, BEXHILL—THE LIBRARY

(*Architects : Erich Mendelsohn and Serge Chermayeff, F.R.I.B.A.*)

into the pores of the concrete wall; it also leaves a semi-smooth appearance. In dry weather the wash is liable to dust up if not kept sprinkled with water every twelve hours for two or three days. One method of preventing this dusting is to use a 3 per cent. solution of commercial calcium instead of plain water when preparing the slurry. The calcium attracts moisture from the air, and preserves the dampness of the slurry for several days until the mixture has set. On the other hand, calcium always attracts moisture, and is thus not an altogether desirable ingredient in a wall surface.

Dash Coats

A very effective finish to a wall formed in shuttering composed of square-edged rough timbers, as already described (Fig. 6), is one known as spatter dash. This is a rich cement rendering mixture, containing 1 part of cement to 1½ part of coarse-graded sand mixed in with 1 part of water, all the ingredients being measured by volume. The mixture should be stirred until it becomes the consistency of a thick cream, and then flung on to the wall from the pail with a whisking motion with a bristle brush. Before applying the spatter dash the concrete face should be wetted down, but not soaked with water, as this will destroy the necessary suction required to make the spatter dash adhere. When completed, this facing should be kept damp for about ten days to allow the cement to set. One way to do this is periodically to spray the walls with water through a rose, but another and better method is to hang damp hessian cloth or kraft paper over the face of the wall. This not only keeps the cement damp, but also protects it from wind and rain until it has properly hardened.

Painting and Staining Concrete

A smooth-finished concrete wall can be painted, provided that special precautions are taken to resist the action of alkalis and damp. The painting should be deferred as long as possible, to allow the water to dry out of the mixture, and the first coat to be applied should be some special inert primer made with waterproof and alkali-resisting oils or synthetic resins. Subsequent coats may be of ordinary oil paint, but it is advisable to use tung oil as a base in preference to linseed oil, as it is more resistant to alkalis.

Concrete can also be stained by means of creosote, ferrous sulphate, or copper sulphate. Before applying either of the sulphates the surface should be damped, and as these do not give even colouring it is recommended that they should not be used for large surfaces or important elevations. Another staining mixture is composed of boiled linseed oil and tung oil, thinned with turpentine or naphtha. Any colour pigment can be added to this base, and a large number of shades is possible.

Precast concrete slabs can also be metal sprayed, and afterwards

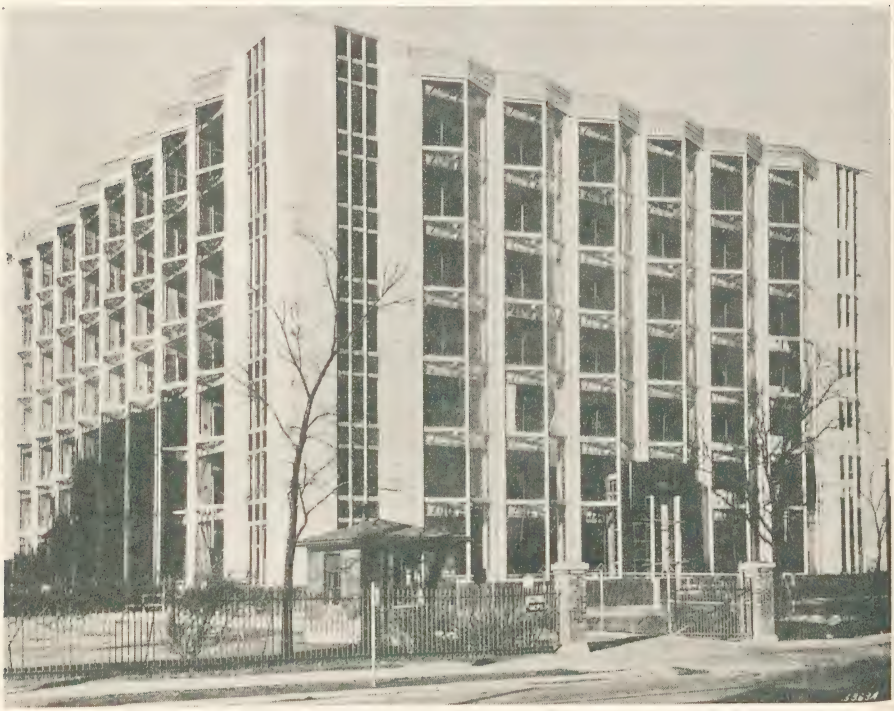


Fig. 7.—A LARGE CONCRETE-AND-STEEL BUILDING IN THE UNITED STATES ENTIRELY FACED WITH ALUMINIUM

polished, but the process is not practicable for inside walls in situ, and should be confined to small cast ornamental parts which are subsequently built in.

ALUMINIUM COVERING

Aluminium is a tin-white metal obtained from certain clays and felspars. In America, where nearly one-half of the world's supply is produced, it has been extensively used for the external facing of buildings, in some cases entirely replacing other forms of wall construction. During the last four or five years nearly all the Federal Government buildings erected under the Public Works Relief Programmes have exhibited aluminium facings of some form or other. One of the largest buildings to employ aluminium facings in New York is the Rockefeller Centre, where more than 17 per cent. of the total external wall surfaces of these 800-ft.-high blocks are faced with the metal.

Weight of Aluminium

It is obvious that the steel framings of such a building can be designed to carry considerably lighter loads with aluminium facings than with

any other type of walling, the metal weighing only 173 lb. per cubic foot, about one-third of the weight of bronze, and one-quarter that of lead.

Steel-framed buildings have been erected with both the inner and outer sheetings composed of aluminium (Fig. 8). The beams and stanchions are entirely enclosed, and the space between inner and outer skins packed with some heat-insulating material.

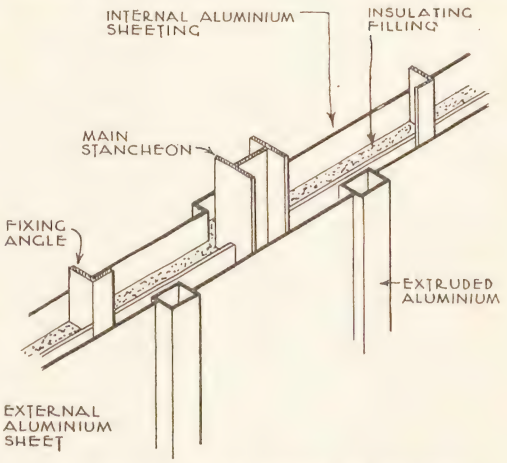


Fig. 8.—ALUMINIUM SHEETS AS WALLING

Aluminium Sheets

Aluminium can be obtained either cast, drawn, extruded, or rolled, in shapes suitable for all architectural purposes (Fig. 9). Standard sheets can be had in sizes from 6 ft. by 3 ft. up to 12 ft. by 4 ft. The thinnest sheets are about 20 S.W.G., and the usual thickness used on large buildings is about $\frac{3}{8}$ in.

In employing the sheets for a wall facing it is usual to combine them with different sections of extruded aluminium mouldings in such a way as to form panels, the extruded sections being fixed to backing plates which in turn are bolted to the main skeleton (Fig. 10).

Galvanic Action to be Avoided

Care must be taken with fixing, for aluminium will set up electrolytic action when brought into contact with steel or bronze. The backs of all castings should be treated with a bitumastic paint, and the bitumen allowed to dry before assembling the parts against steel work. Another method is to introduce strips of insulating fibre between the two metals.

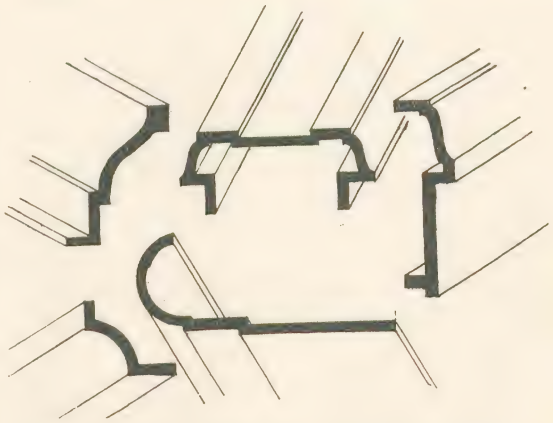


Fig. 9.—SOME EXTRUDED ALUMINIUM SECTIONS

An American Building

The external walls of the new Public Works

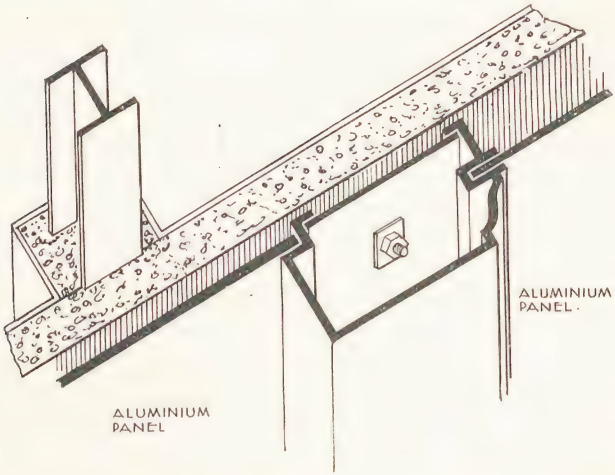


Fig. 10.—EXTRUDED ALUMINIUM PILASTER WITH BACK PLATE BOLTED TO CONCRETE

Building in Richmond, U.S.A., are composed of two facings spaced about 7 in. apart, packed with insulating filling, all of which weighs less than 10 lb. per square foot. The aluminium pilasters were assembled at the shop, and consist of a frame of extruded sections about $\frac{1}{8}$ in. thick. The panels between the pilasters were of similar thickness. These pilasters are 25 ft. high and 3 ft. wide. All joints between vertical and horizontal members are welded. The panels, which are 6 ft. in length, fit into grooves in the mouldings of the extruded members. Insulating material is filled in from the bottom of the wall up to 1 ft. above the roof girders, and tests have shown that the heat loss through this type of construction is equal to that through a 48-in. brick wall.

Aluminium Cast Panels

Aluminium cast panels are suitable for external ornaments, being less brittle than cast iron and considerably lighter, but with all such castings pockets likely to hold rain-water should be avoided.

Hardening Material

Silicon is the hardening element used in architectural aluminium, the quality of castings depending upon the quantity of silicon they contain, which should never be less than 5 per cent. For external work in humid atmospheres, all aluminium should first be anodised in the manner described later for " Birmabright " alloy.

" Birmabright "

Among the various aluminium alloys which are becoming increasingly popular for various purposes in modern life—such as aeroplane castings or speed-boat construction—" Birmabright " has also a definite use in building construction. It is obtained in sheets, extruded moulded sections, and castings, and is employed extensively in interior work in all these various forms. So far it has not been widely used in this country

for exterior sheeting, although the strips and beadings used in many glass-fronted structures, to secure the glass sheets, are of this metal. But provided it is treated properly before erection, there is nothing in " Birmabright " to prevent its satisfactory application as an external covering to a building. It is a very light metal, weighing approximately one-third of similar-sized sheets of steel, copper, or bronze, and being produced without a heat treatment is easy to work both in sheet metal and in extruded moulded forms.

Rolled Sheets

The sheets are manufactured in three grades of temper—hard, half-hard, and soft, and they can be obtained in thicknesses varying from 26 S.W.G. up to $\frac{1}{2}$ in. The largest sheet normally obtainable is one of 14 ft. by 5 ft.

When applied to interior work without special treatment, " Birmabright " metal will retain its bright colour, and it will also do this in a really dry atmosphere when used externally. But such climatic conditions do not exist in England, and all sheets or sections used externally in this country must first be anodised.

Anodising

The anodic oxidation treatment produces on the metal sheets a tough tenacious film which has a very high resistance to corrosion. A variety of shades can be produced by anodising, from a light antique silver to a frosted matt finish, the latter being the more durable. The anodising is applied to the various sheets and sections just prior to assembling them on the job, and after all welding or wrought work has been completed.

All anodised surfaces should be given a periodical treatment with a wax polish, which preserves the waterproof qualities of the metal, and prevents the dulling of the surface colour.

Welding

Sheets of " Birmabright " alloy can be satisfactorily welded with an oxy-acetylene lamp and a welding stick of the same metal. It is, however, inadvisable to use solder in forming the joints, for the two metals will between them set up electrolytic action ; the colour of the joints will also become very noticeable, as these will rapidly blacken. If a soldered joint is absolutely unavoidable it should be concealed and used only in interior work, since a solder joint cannot be anodised.

Cleaning

Anodised surfaces, as stated above, very seldom require to be cleaned, but when the work is undertaken a sponge and warm water should first be used to remove all dirt from the sheets. " Birmabright " used

By courtesy of The Carron Co. Ltd.

Fig. 11.—MESSRS. HARVEY NICHOLS' PREMISES, LONDON

Ornamental cast-iron wall panels of the upper three floors secured to the main frame of the structure and fixed between stone pilasters.

internally can be kept bright by polishing with a preparation such as "Silvo."

The "Birmabright" alloy has one advantage over some other metals in connection with stonework, in that it will not stain the surrounding masonry by streaking it.

CAST-IRON COVERING

Cast iron is still one of the popular coverings for walls. Cheaper than stone, it presents little difficulty in fixing to the steel skeleton. This metal can either be supplied as panels, fixed between stanchions or stone piers and continuing through several floors, or be employed as a complete casing to the building, enclosing the stanchions and forming the walls between them. Pilasters and stanchions under windows are secured by bolts to the horizontal and vertical members of the steel framing, and drawn up lightly to them. This provides a rigid walling, and any backing required to ensure insulation is carried by the floors quite independently of the metal facing.

The Castings

Small castings are generally about $\frac{1}{4}$ in. thick, but large castings require greater strength and are usually from $\frac{3}{8}$ in. to $\frac{1}{2}$ in. thick. Joints should be machined when possible, but where this cannot be done, a weather strip on the inside of the joint is usually provided as an alternative. The surface of cast iron must be protected, and castings should have been given a coat of boiled oil and red-lead paint before being dispatched to the job. As soon as the work is fixed a second coat of lead paint should be applied to prevent rusting, and the finishing coats can then be left to be carried out with the painting at the completion of the work. A well-painted cast-iron front should not require further attention for at least seven years.

Protective Coatings

Certain manufacturers have experimented with various types of protective materials. One of these is a copper surface electrically deposited, which is satisfactory provided that no pinholes are left to allow wet to penetrate under the copper coating. Another is cellulose, which can be carried out in a variety of colours ; and a third consists of spraying the iron with either zinc, copper, or bronze. The drawback of these processes is their cost, and it is doubtful if in the long run they are more economical than periodical painting.

QUESTIONS AND ANSWERS

How is a Reinforced-concrete Wall faced with Stone Slabs of about 2 in. in thickness ?

There are two methods generally adopted.

(1) The slabs are placed in contact with the concrete and secured by cramps to the concrete.

(2) The slabs are carried about 2 in. clear of the concrete wall, being secured by means of rustless metal ties. When this method is adopted the insulating material is sometimes placed on the outer face of the concrete.

How are Reconstructed Stone Slabs, having dovetailed grooves, erected ?

The slabs are first placed in position, the shuttering built up, and the concrete then poured behind the slabs. The liquid mass is carefully rodded into the dovetailed angles in order to bond the stone and concrete wall together into a homogeneous mass. Walls thus constructed are built up in vertical heights of about 3 ft. Care should be taken to see that the walls are always plumb.

What are the stock sizes of Terra-cotta Slabs or Panels ?

From 24 in. by 12 in. to 12 in. by 9 in.

How are Terra-cotta Blocks and Slabs fixed ?

Blocks are best fixed while the reinforced-concrete wall is being built.

The slabs are applied by means of a cement and sand rendering.

What was the method of construction employed for the Precast Concrete Slab Facing of the Dorchester Hotel, London ?

The precast slabs were used as the outer face of the shuttering. A 2-in.-thick layer of cork was employed for the inner, and the reinforced-concrete wall was joined in between them. The slabs were about 2 ft. long, 1 ft. high, and 2 in. thick.

What is Spatter Dash coating ?

A rich cement rendering mixture, containing 1 part of cement to $1\frac{1}{2}$ part of coarse-graded sand mixed with 1 part of water, is applied to the wall from a pail, with a whisking motion, with a bristle brush.

ROOF CONSTRUCTION

PART II.—VALLEY, TRUSSED-PURLIN, AND SINGLE MANSARD ROOFS

ANOTHER form of roof is the valley or double lean-to (see Fig. 1). The roof is inclined from the party or main walls, towards a gutter in the centre usually over a partition wall or some other support. The rafters rise from a pole plate, or sometimes from a pair of parallel plates which form the sides of the gutter, and which are supported by a partition. The upper ends of the rafters are carried on plates resting on wrought-iron or brick corbels from the party walls. The front of the building is usually finished with a wall and parapet, and the back of the building with gable ends, the roof finishing with a verge.

Purlins

Purlins are horizontal members introduced to provide an intermediate support to the common rafters, and in turn are supported by gable walls, roof trusses, or by the use of struts supported on partition walls where the rafters are hipped on each end. Care should be taken that the struts, when used, have a good bearing at their feet. Stud partitions, rising from a timber floor below, are not altogether satisfactory.

Spacing of Purlins

The spacing of the purlins is governed to a large extent by the roof covering, and to some extent by the type of roof design. In order that the common rafters may have economical dimensions, the purlins that carry them require to be within a spacing of not more than 10 ft. The purlins should be placed in position before the rafters are fixed, although they are sometimes added afterwards.

Trussed Purlins

Where, owing to the length of the roof, the purlins would become inconveniently large (see Fig. 2), a useful construction that may be used, and might be more often adopted, is the trussed purlin. It will also be found suitable where there is not the necessary room for a principal, and the space inside the roof is to be utilised.

The purlins should extend from wall to wall, and rest on stone templates built into the wall. They should be kept clear of the floor joists, otherwise, when wind pressures come suddenly on one side of the roof,

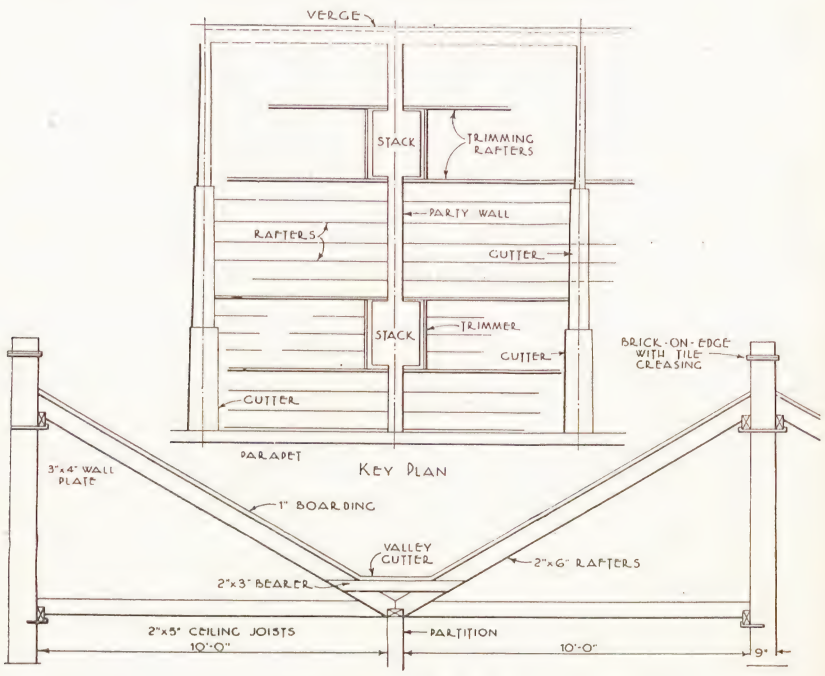


Fig. 1.—VALLEY ROOF

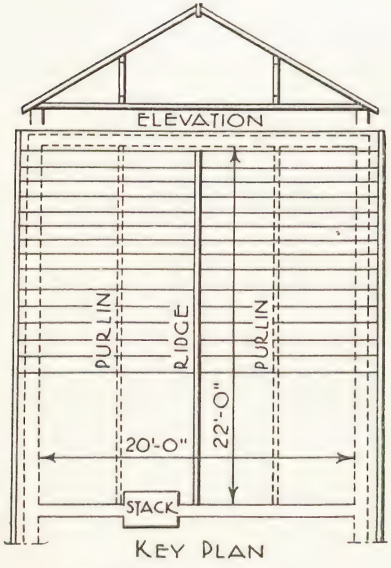


Fig. 2.—PURLIN ROOF

the trussed purlin would consequently be subjected to stresses which might cause sufficient deflection to crack the plaster ceiling below. The bottom member is usually made 4 in. by 4 in., and the struts 3 in. by 4 in., with $\frac{1}{2}$-in., $\frac{5}{8}$-in., or $\frac{3}{4}$-in. bolts, but, if desired, the stresses could be calculated to obtain the exact sizes required (see Fig. 3). The truss usually forms the ashlaring along the sides of the room, and may be filled in with studding to receive the plaster or to be covered with a fibre board.

Roofs Constructed of Short Timbers

Other simple types suitable for comparatively large spans can be built up by placing pieces of various lengths side by side with the use of a truss. In these types it is usual to place the two rafters a few inches apart, to allow for

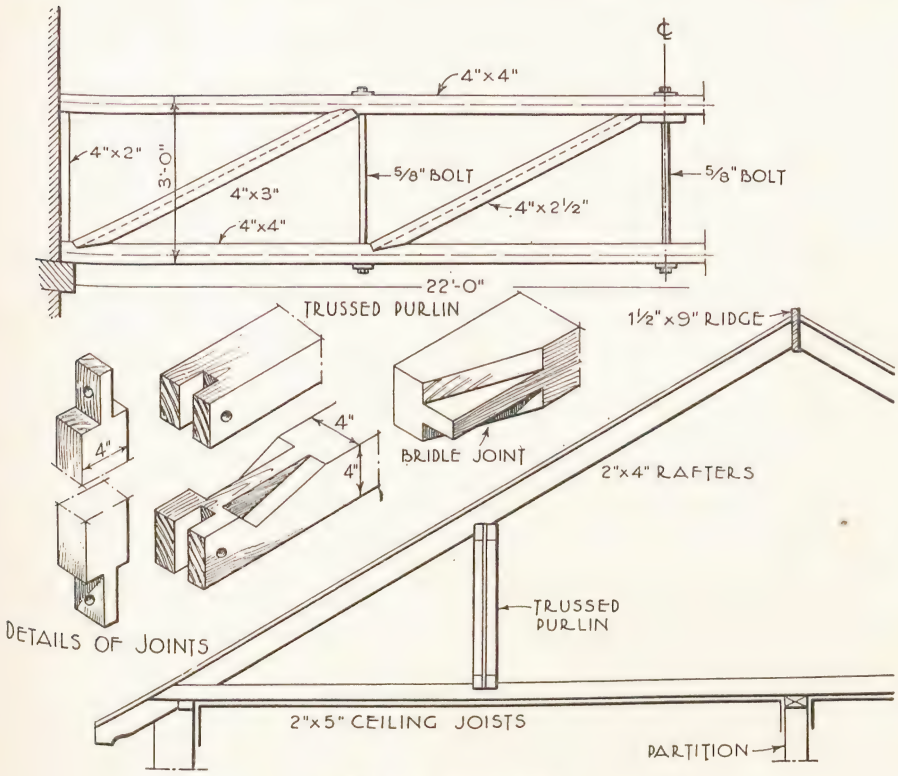


Fig. 3.—PURLIN ROOF

the internal members being fitted securely between the built-up rafters and main tie. The members A, in Fig. 4, are formed at their ends with shoulders which bear on the double rafters and the members, and part formed to extend between the rafter and tie as a tenon. Member B is similar, excepting that at the lower end it notches over the ties and finds a bearing on them. The rafter back near the apex of the truss is formed with two 2-in. by 5-in. pieces placed together, one acting as a joint-plate in lieu of a fish-plate.

When properly fastened together by nailing and bolting, the short pieces are equally as strong as single pieces, and are cheaper and easier to obtain.

SINGLE MANSARD ROOF

This type is being much used in domestic work. For small spans, it provides an economical means of containing and roofing upper floors and bedrooms. When properly built, it is constructionally sound, and

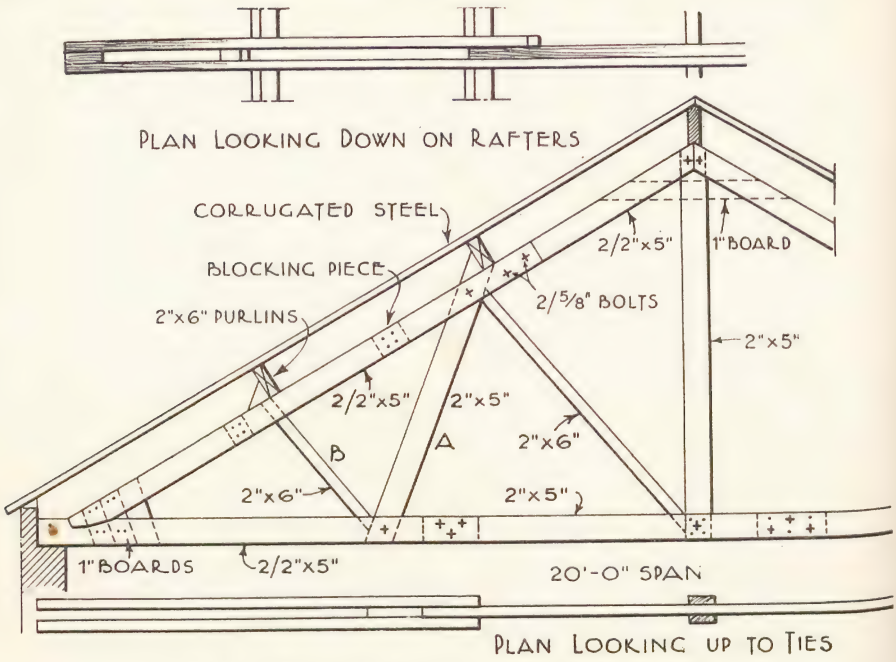


Fig. 4.—ROOF CONSTRUCTION OF PIECES OF TIMBERS

also capable of pleasing architectural treatment. It is unnecessary to use trusses to support this type of roof over small spans up to 20 ft.

Outlines of Mansard Roof

There are many variations in the outline, usually obtained by using one or other of the original French methods of setting out adopted by Mansard, the inventor. Fig. 5 shows the methods used. A semicircle is drawn equal in diameter to the effective span. This is divided into four or five equal parts, giving slightly different outlines. In some cases the lower pitch is inclined at 60° until sufficient headroom is obtained, and then the upper slope inclined at 30°. In modern work the lower slope is usually made 75°, which is the maximum allowable under the Building Acts. For small buildings the lower slope is inclined at 75°, and the upper at from 26° to 45°, according to the covering used.

Construction

To obtain the maximum amount of room it is usual to finish with gable-end construction, at least to the height of the lower pitch or kerb. Fig. 6 shows a type commonly adopted, as it gives more floor space. The type shown in Fig. 7 is of stronger construction, but a certain amount of floor space has to be sacrificed. Additional strength can be obtained

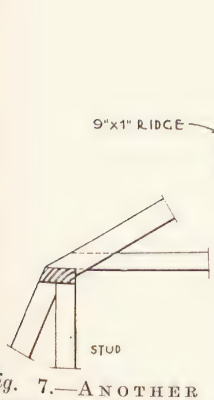


Fig. 7.—ANOTHER TYPE OF MANSARD ROOF CONSTRUCTION

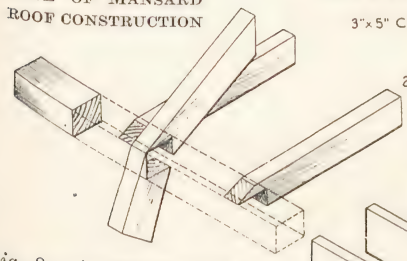


Fig. 8.—ALTERNATIVE METHODS OF FINISHING AT CURBS

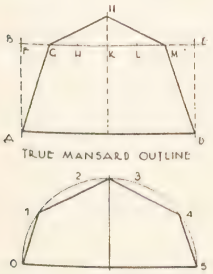


Fig. 5.—TYPICAL OUTLINES OF MANSARD ROOF

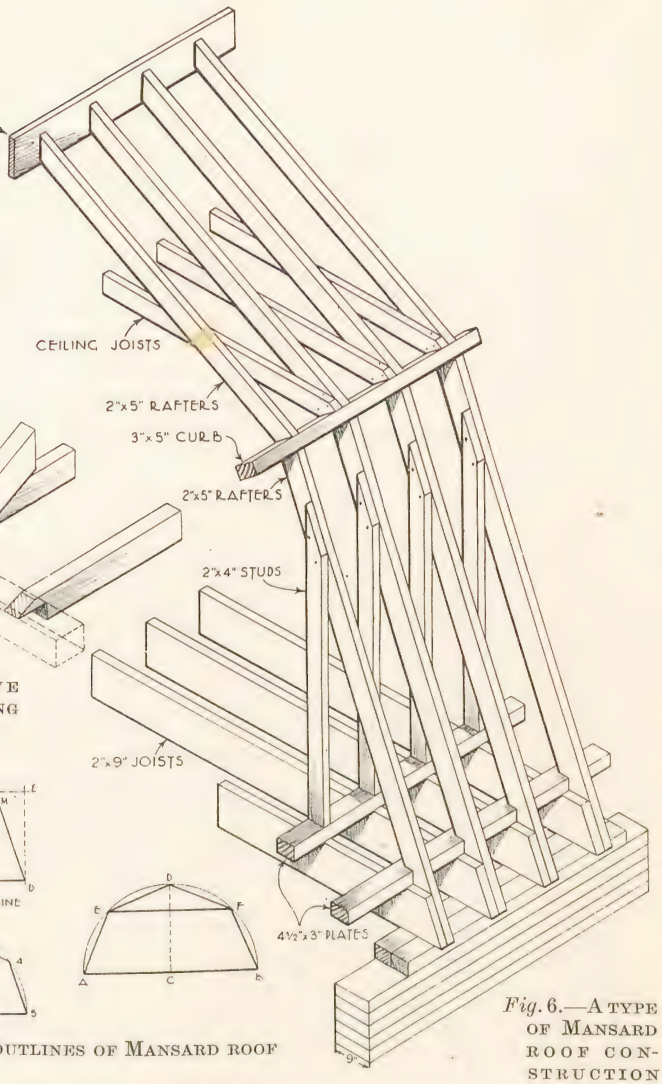


Fig. 6.—A TYPE OF MANSARD ROOF CONSTRUCTION COMMONLY ADOPTED

Figs. 5 *to* 8.—SINGLE MANSARD ROOF DETAILS

by nailing cross-pieces between the ashlaring or upright pieces and the rafters, usually about every fourth member. This bracing will considerably stiffen the frame and lessen its liability to rack. The rafters should be bird's-mouthed to the wall plate, and also fixed to the side of joists. This will help to stiffen the roof. Every fourth or fifth stud should be tenoned into the cill and curb. Where wind bracing is employed, the

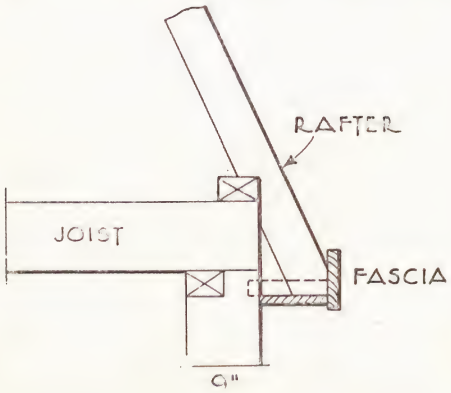


Fig. 9.—EAVES OF SINGLE MANSARD ROOF FINISHED WITH FASCIA

tenoning of the studs may be omitted provided the joints are well made and securely fixed. The floor joists will vary in depth according to span. They are often supported at intermediate points by party walls or partitions.

An alternative method of finish at the curb is shown in Fig. 8, and the finish at the eaves in Fig. 9.

Types of roof construction for larger spans are dealt with in later sections.

QUESTIONS AND ANSWERS

What is the maximum spacing for Purlins ?

Ten feet.

How are Trussed Purlins supported ?

On stone templates built into the walls.

Why should Trussed Purlins be kept clear of Floor Joists ?

Because sudden wind pressure on one side of the roof might deflect the trussed purlin sufficiently to crack the plaster ceiling below.

In what cases is Trussed-purlin construction useful ?

(1) Where, owing to the length of the roof, the purlins would become inconveniently large.

(2) Where there is not the necessary room for a principal, and the space inside the roof is to be utilised.

How is the space inside a Roof with Trussed-purlin construction usually finished if it is to be utilised as a Room ?

The truss usually forms the ashlaring along the sides of the room, and may be filled in with studding to receive the plaster or to be covered with fibre board.

BOUNDARY FENCE CONSTRUCTION

THE erection of a fence is rendered necessary for either one or both of the two following reasons : (1) to define the boundary of an estate or property, and (2) to protect the property. In the first case it may be constructed in the very simplest manner by posts and wire, and in the second it may have developed into a very substantial wall. Between these two extremes is a very wide margin, giving scope for design and construction in various and widely differing materials, such as wire, cast or wrought iron, wood, brickwork, natural stone, concrete, and artificial stone.

THE WIRE FENCE

The Simplest Kind

The simplest kind of fence is perhaps three strands of wire, attached by staples to wood posts. This, of course, will define a boundary, but is no protection whatever, unless barbed wire be used, which is not perhaps a desirable material. In later years concrete posts have been employed, especially on housing estates. The wires are usually formed of seven strands each, passing through holes in the post, with a hook to secure a loop at the end of the wire. The wires are strained or tightened by a bolt attached to the hook at the end post. The writer has observed that this form of construction has not always been a success, because in a few years the concrete has often been flaked off by the weather and left the " bones " or reinforcement of the concrete exposed, probably on account of the concrete not being thick enough to give adequate protection to the reinforcement.

The ordinary wire-netting, such as used for fowl runs, etc., can hardly be taken seriously as a definite boundary fence, though it is often utilised along the base of a natural hedge, to keep out dogs and other undesirable quadrupeds.

" Hercules " or " Crusader " Fencings

A great advance on this type of fence is systems like the " Hercules" or " Crusader " fencings. These are made of strong-gauge wires, roughly about $\frac{1}{8}$-in. diam., galvanised after manufacture. The former consists of a horizontal and vertical mesh. The horizontal wires are at approximately 6-in. centres, vertical wires as desired being either 6 in. or 12 in. apart. The main supports for carrying these fencings consist of $1\frac{1}{2}$-in. by $1\frac{1}{2}$-in. L iron standards, 15 ft. apart. Fig. 1 shows this type of fencing.

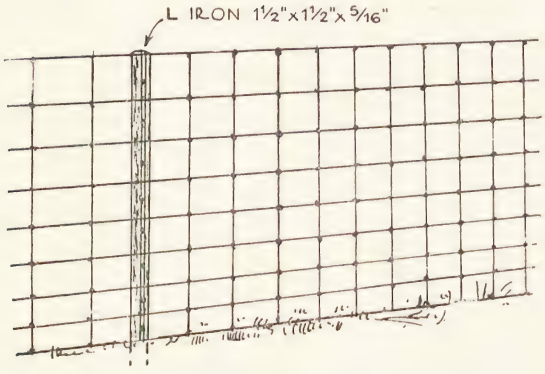


Fig. 1.—A USEFUL TYPE OF WIRE FENCING

Straining pillars with a stay are required at the end of each run of fencing. Incidentally, any pillar or intermediate standard is all the better for being set and packed in concrete.

Chain Pattern

Another useful type of a wire fencing is the chain pattern (see Fig. 2). This is made in different varieties of mesh, but about 2-in. is the most popular. As will be seen from the figure, this is difficult to climb, and is obviously a much more expensive form of fencing than the type shown in Fig. 1.

WOODEN FENCES

All wood fences should be creosoted or treated with some wood preservative before being erected. This applies most strongly to the main posts, particularly to the ends which are sunk 18 in. to 2 ft. into the ground. In many cases these ends are tarred, and sometimes a wood socket is made of $1\frac{1}{4}$-in. boards (Fig. 3), which is particularly necessary in the case of a fence for protecting a cricket pitch, where the posts are constantly being taken up and refixed. Flat wood covers are provided for covering the sockets when the pitch is in use. Concrete may be used at the base of a post where the fence is not likely to be moved.

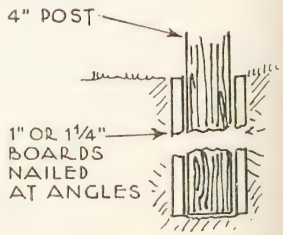


Fig. 3. — SOCKET FOR WOODEN POST

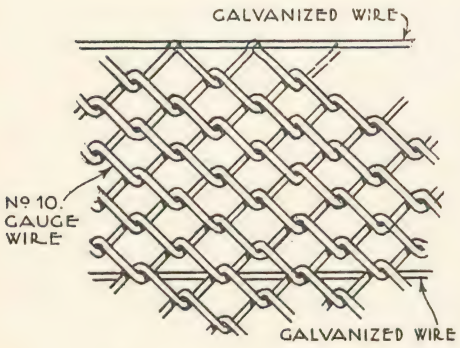


Fig. 2.—CHAIN FENCING

The Simplest Form

The wooden fence may be of either the open or the closed pattern. The simplest form is, of course, posts and three or more rails. Next to this comes the ordinary fence of the same character, but filled in with wooden splats, about 3 in. by $\frac{3}{4}$ in., with either square or pointed ends.

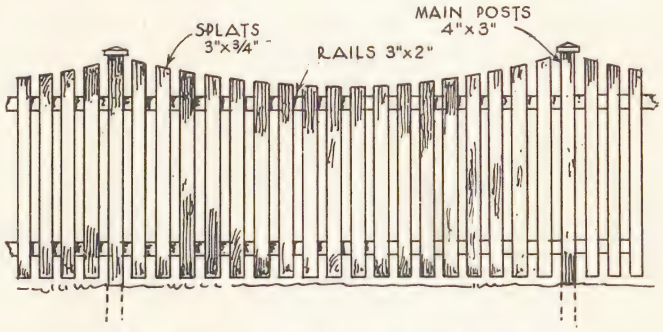


Fig. 4.—ORDINARY " SCALLOPED " FENCE

Very often, to give a little character, the splats are cut to a gentle curve or scalloped (Fig. 4). Occasionally, only every alternate splat or every alternate pair is cut to the curve (Fig. 5). A very economical form of splat is obtained out of " spout screed," or the wastage sawn from a wooden spout before it is run through the machine (Fig. 6).

Cleft-chestnut Construction

The cleft chestnut fence consists of a series of cleft chestnut pales attached to strong wires which, in their turn, are secured to posts by staples. It is an economical form, and the price naturally varies according to the height of the fence and the closeness of the pales, as the latter may be from 2 in. to 5 in. apart. It may be varied by using long and short lengths alternately, as Fig. 7.

Fig. 6. — ECONOMICAL FORM OF SPLAT SAWN FROM WOOD SPOUT OR EAVES GUTTER BEFORE MACHINING

Woven-board Fence

Probably the " woven-board " fence is as good-looking as any class of wooden fence, the panels between the posts being formed of interwoven deal slats 4 in. wide by $\frac{1}{8}$ in. or $\frac{3}{16}$ in. thick (Fig. 9). As these are usually made in panels, and nailed to the main posts, the fixing is very simple. This fence requires a horizontal " gravel board " at the base, and a capping, the latter being either bevelled or moulded. If the whole is surmounted by a simple square trellis, and the posts taken up 3 or 4 in. above the trellis, this fence has a very pleasing appearance.

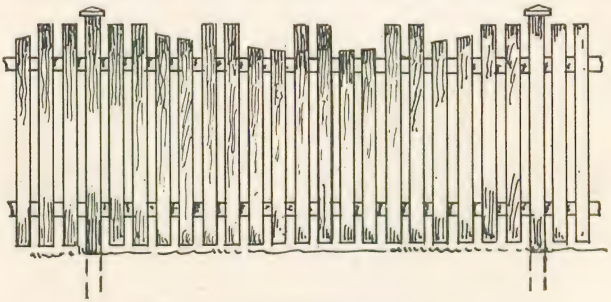


Fig. 5.—ALTERNATIVE SCALLOPING

Close-boarded Fence

The close-boarded fence of riven oak is

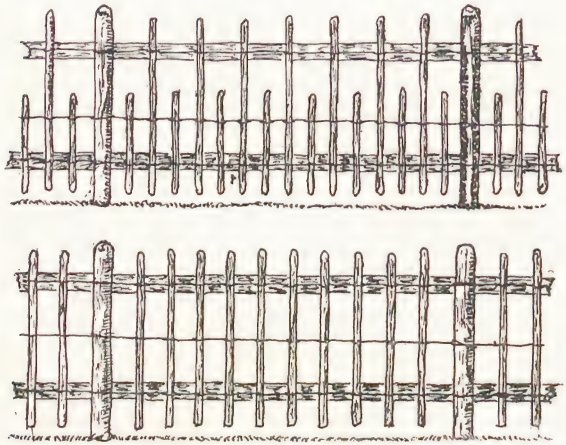


Fig. 7.—ALTERNATIVE TYPES OF CLEFT CHESTNUT WITH RUSTIC POSTS

a very attractive type. A good fence is generally formed of 5-in. by 4-in. posts 2 ft. in the ground, and two or three horizontal rails, covered with 3½-in. by ½-in. boards slightly overlapping. A "gravel board" is also required, and capping similar to the "woven-board" fence (Fig. 10).

This fence can also be surmounted by trellis; in fact, trellis alone can be employed as a fence, but if of a moderate height must be of a little stouter construction.

Wattle Construction

It would scarcely complete the series of close fences without mentioning the "wattle." This kind is simply formed by hurdles about 6 ft. long, each consisting of eight or nine slender stakes of ash, hazel, or similar wood, with strips of half-round hazel wood interlaced (Fig. 8). This class, however, is rarely employed as a fence, but is more often utilised as a shelter for newly set plants, to protect them from strong winds. In Holland and Belgium the writer has seen wattles employed to protect canal banks from erosion caused by the wash created by the passing of barges.

A great variety of fence designs can be obtained by scalloping, the combination of trellis with vertical or woven boarding, or the arrangement and grouping of ordinary open splats.

Strengthening the Wooden Fence against the Wind

The wooden fence, if it is 4 ft. or more in height, should be strengthened against the wind. This is occasionally a matter of some little difficulty. Obviously, if the direction of the prevailing wind is from the outside, the posts should be propped. Usually a diagonal strut, cut to the correct angle and nailed to the post, with the lower end nailed to a stout peg well driven in to the ground, is sufficient. But if the direction of the wind is generally from the inside, it is clear that the post will tend to be drawn

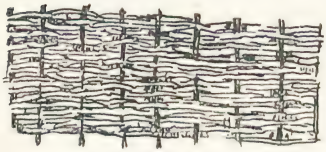


Fig. 8.—WATTLE HURDLE

away from the nail, therefore the raking strut should be used as a tie, and nailed sideways to both peg and post. Two nails might be used at each joint, and if the raking tie be notched to both peg and post it is better still. Fig. 11 will explain the construction of the supports.

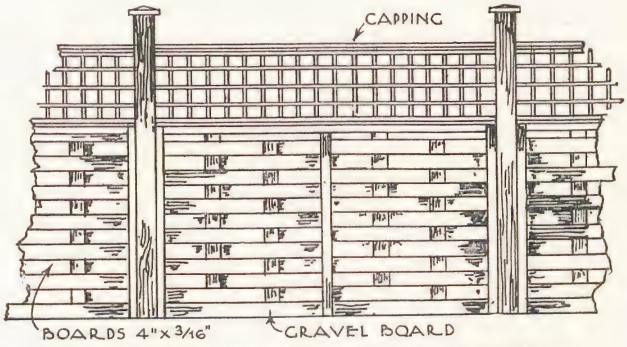


Fig. 9.—WOVEN-BOARD FENCING AND TRELLIS

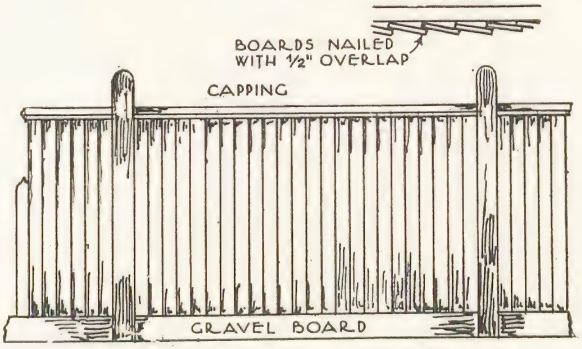


Fig. 10.—RIVEN-OAK FENCE

BRICK BOUNDARY WALLS

Retaining Walls

In cases where the private property is considerably higher than the public road, as so often occurs, a wall is absolutely essential to keep up the ground. The brickwork in this case must act as a retaining wall, and it is very doubtful if a 9-in. wall is sufficient for this purpose, though naturally this depends on the height required. Its strength can always be assisted by giving it a slight batter, or slope inwards. The ordinary method of strengthening a brick wall is by buttresses, but in the case mentioned the buttresses must naturally be on the inside of the wall.

In the reverse case to the one above described, that is, where the garden is lower than the public road, the same remarks apply.

Like the wood fence, the

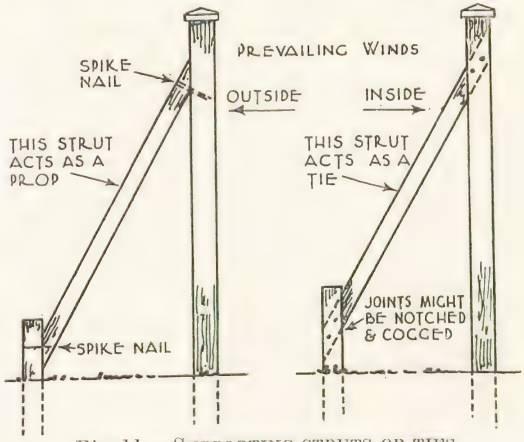


Fig. 11.—SUPPORTING STRUTS OR TIES

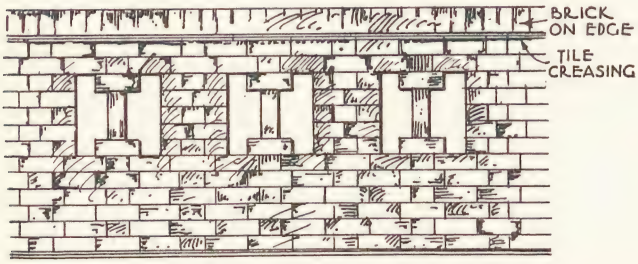


Fig. 12.—LOOPHOLED BRICK WALL

brick wall may be either open or close.

Decorative Work

If the former be decided upon there is plenty of opportunity for design in forming a series of loop-holes, as in Fig. 12. Attractive panels can be introduced by the use of half drain pipes (Fig. 13). As the brick wall is as a rule only 9 in. thick, it is usual to construct it with 14-in. square piers, the wall between being either a dwarf wall or full height, say to within 12 in. of the piers. If the wall be of the dwarf variety, the panel is filled in with wood or iron railing, to which we shall refer later.

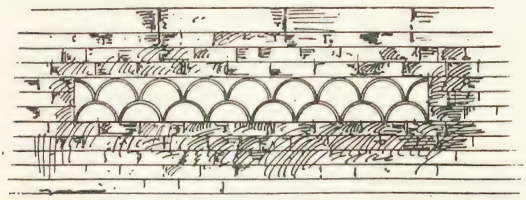


Fig. 13.—PANEL IN BRICK WALL FORMED WITH 9-IN. HALF-PIPES

Variety can be obtained by using bands of bricks of a slightly different colour, choosing a dark shade for the base, stock bricks for the general walling, with a band of red or brown brick, or introducing panels of bricks on end, or "soldiers." Fig. 14 shows a "diamond" pattern which might be carried out in either the ordinary brickwork or a specially selected colour.

Copings

The coping may be of double "bull-nosed" bricks, half-round, or a simple bevelled one of either natural or artificial stone. If the wall be thick enough, a "roof" formed of two courses of pantiles makes a very artistic finish, but this could not be carried out with a 9-in. wall. Fig. 15

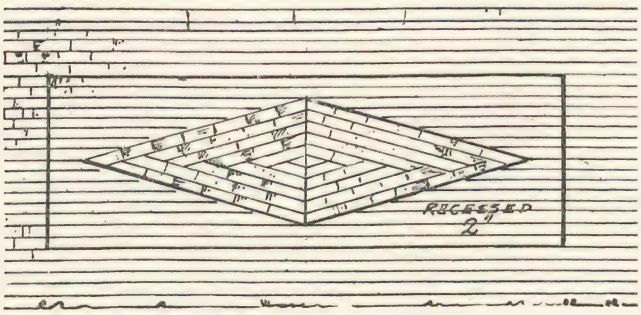


Fig. 14.—DIAMOND PANEL IN BRICK WALL

gives an idea of a wall finished in this manner, such as can often be seen in some old villages. It is not, however, a desirable finish unless the wall be high enough to prevent damage to the tiles by mischievous children.

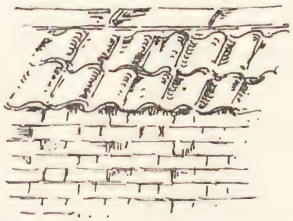


Fig. 15.—PANTILE COPING

A brick wall may be finished brick-on-edge, set in cement, either with or without tile creasing. There is also the choice of a natural stone coping, moulded if expense will allow, with artificial stone, concrete in situ, and various forms of specially made terra-cotta copings. All these special copings should be made with the necessary mitres and returns that the buttresses and stopped ends may require.

A cheap method of wall construction is that often employed by the speculative builder. The boundary is defined by erecting a series of 9-in. or 14-in. square piers, each with a plain square flag as a cap, and the space between simply filled in with 3-in. concrete slab, and plastered. This system cannot be recommended, but for the time being it serves its purpose and gives a very cheap protection to the property.

STONE WALLS

A stone wall is of course a delightful boundary, but it is not desirable to use it unless it is in harmony with the character of the buildings. The old type of walling, which the text-books describe as "regular coursed rubble," or "squared rubble built to courses," looks the best. Piers built at intervals, finished with suitable caps, are desirable, and if the piers are of dressed ashlar it most certainly enhances the appearance.

If the wall is a substantial one, both in height and in thickness, such as one of the old-fashioned limestone walls, say 6 ft. or more in height, the pantile coping shown in Fig. 15 makes a very charming finish.

The dry walling so common in Scotland and on the Yorkshire moors is scarcely suitable as a boundary wall except in the most rural surroundings.

IRON FENCINGS

The final type of fence or boundary indication to be described is the iron one. Here there is such a wealth and variety of design and workmanship that it is difficult to know where to begin and, still more difficult, to know where to finish. We can, for example, employ the light hurdle, 6 ft. long, with three or more horizontal rails. From this type to the elaborate wrought-iron railing, with its numberless scrolls and twists, the variety of design is bewildering.

"Unclimbable" Fencing

There is the useful type of unclimbable fencing, with main standard bars of flat iron about $1\frac{1}{2}$ in. wide by $\frac{1}{2}$ in., usually having two prongs

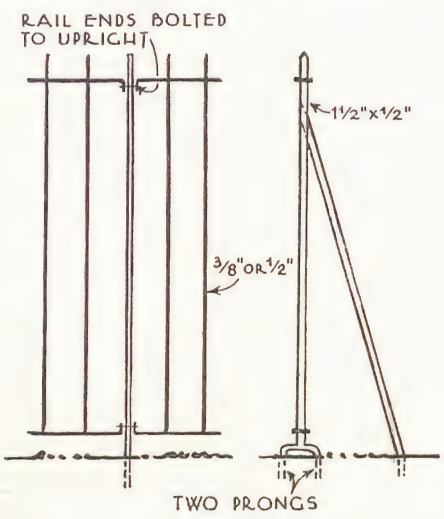


Fig. 16.—UNCLIMBABLE IRON FENCING

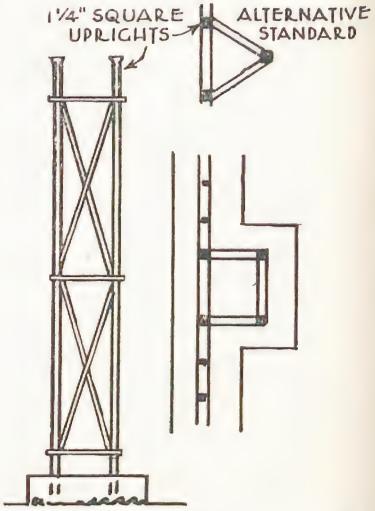


Fig. 18.—USE OF STANDARDS FOR IRON FENCING SET IN COPING

firmly fixed in the ground. These carry horizontal rails, top and bottom. The intermediate bars are ⅜-in. or ½-in. diameter, and are usually spaced at 5-in. to 6-in. centres. If preferred, a square bar may be used instead of a round one. This fencing, to justify its name of "unclimbable," should be at least 6 ft. high. In cases like this, where the fence is merely fixed in the ground, every main bar should have a stay (see Fig. 16).

Dwarf Wall Rail Finish

It is impossible and it is not desirable to attempt to describe the many types of railing employed as a finish to the dwarf wall. If piers are used the railing may be considered as a series of panels between the piers (Fig. 17). The construction, in a simple case, is usually two horizontal rails about 1½ in. by ½ in., built into the pier at each end, and the vertical bars, about ⅝ in. or ¾ in. square, welded to the rails at 4-in. to 6-in. centres. Some of the uprights should be let in to a mortice in the coping, and run with lead. A common practice is to form a scroll panel in the centre of each length of railing.

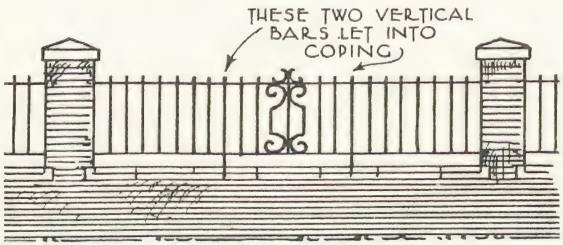


Fig. 17.—RAILINGS WITH SCROLL PANEL EMPLOYED AS FINISH TO DWARF WALL

If the wall be of the dwarf pattern, but having no piers, it is advisable to have a greater number of mortices, owing to the long length of railing. The wall should be provided with buttresses at each end and approximately at 9-ft. or 10-ft. intervals, to allow for a raking strut to be " leaded " in, and thus stiffen the railing.

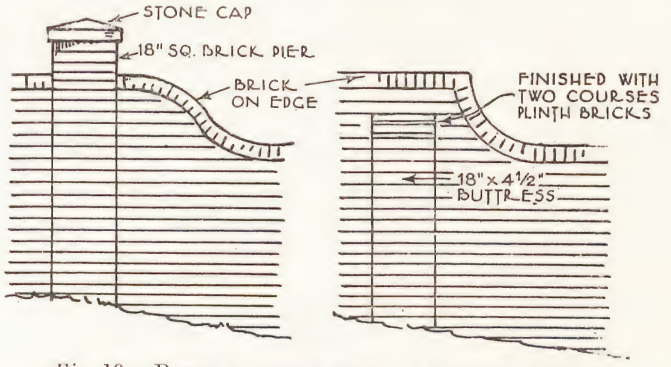


Fig. 19.—RAMPS TO BRICK WALL ON SLOPING GROUND

Many speculative builders employ a length of wooden fencing of the type shown in Fig. 4, instead of iron.

In many cases the dwarf wall is almost eliminated and has simply become a coping laid evenly on the ground, with unclimbable fencing fixed upon it. Owing to its height, struts should be liberally provided. Instead of the usual raking stay-bar, a " standard " might be erected, as Fig. 18. This illustration shows the standard as being composed of four strong uprights about $1\frac{1}{4}$ in. square, and braced together. This makes for variety from the ordinary raking strut, and a further change can be introduced by forming the standard in a triangular pattern, employing three uprights instead of four.

The railings above described are usually of wrought iron. The heavy cast-iron railings beloved of the Victorian era are now rarely seen.

Fences on Sloping Ground

If the ground is on the slope the point to be decided is : shall the fence follow the slope of the ground, or shall it be " stepped " ? In the case of a wall there is really no choice—it should be a series of steps ; but with a fence either method may be adopted. Broadly speaking, if the slope be gentle and uniform, a wood or iron fence can follow the inclination of the ground, but if the gradient be steep, steps are more desirable.

Where the system of " steps " is adopted it looks decidedly better if the individual steps be not too abrupt, and the appearance is improved if, instead of a step, there be a ramp of curved brickwork (see Fig. 19). If iron

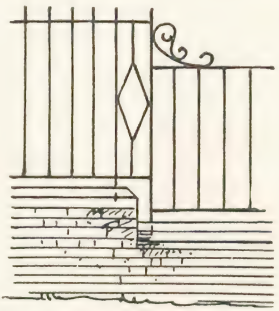


Fig. 20.—RAMPS AND SCROLL FOR IRON FENCE

railings are employed, a scroll of wrought iron at the junction of the two levels relieves the crudity of the step (see Fig. 20).

A system of posts and chains defining a boundary cannot be called a fence, but is a method often employed to mark out the fore-court of a public or other building, and to give more dignity and importance to it. The posts are usually of natural or artificial stone, set in a concrete bed, and to give the proper effect must be of very substantial character. The chains are of an ornamental pattern, hung slackly to form a curve between each post, the centres of the posts varying from 10 to 15 ft.

Occasionally a round or square bar fixed diagonally is used instead of chains.

Finally, employ the class of fence, whether it be wire, wood, iron, or masonry, that will be most in accordance with the character of the building.

The subject of fences leads automatically to entrance gates and their piers. These form the subject of another article.

QUESTIONS AND ANSWERS

What is a Woven-board Fence ?

A class of wooden fence in which the panels between the posts are formed of interwoven deal slats about 4 in. wide by $\frac{1}{8}$ or $\frac{3}{16}$ in. thick. A gravel board is placed at the base, and the top is finished with capping.

How far should main Wooden Posts be sunk into the ground ?

Eighteen inches to 2 ft.

When should a Wooden Fence be strengthened against the Wind ?

When it is 4 ft. or more in height.

What is " Unclimbable " Fencing ?

This term is usually applied to iron-bar fencing 6 ft. high or over.

SKIRTINGS

A SKIRTING board is usually considered to mean the internal plinth applied to the base of a plastered wall. Its primary function is to protect the wall surface, with its applied decoration, from the haphazard damage caused by the sundry knocks of human feet, furniture legs, brooms and scrubbing brushes, and also from the effects of the water used in cleaning the floors adjacent. Against such wear and tear the tough, fibrous nature of wood is a sure shield for the friable, easily chipped, and porous plaster, and its usual applied decoration of paint, distemper, or wallpaper.

Decorative Effects with Skirtings

Its effect is also decorative, for, as the cornice forms a border at the top of a compartment, crowning the enclosing walls, so does the skirting form one at the bottom, adding dignity and an appearance of strength in providing a base.

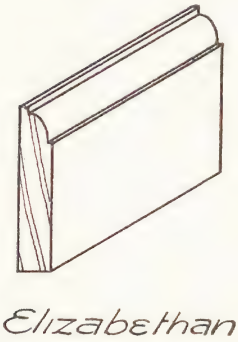
Moreover, the skirting forms a very "clean" finish at the base of a plastered internal wall or partition, simple in practice, being merely a plain or moulded board fixed to, and covering, the plasterer's screed.

Materials Used

Hard-wearing and durable materials other than wood may be used for skirtings: their object is the same; but although they may be more suitable in certain circumstances, they are not in general use.

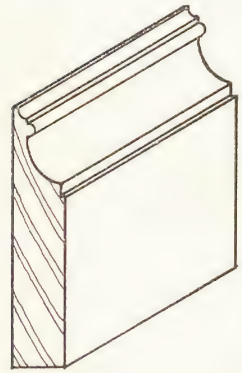
DESIGN

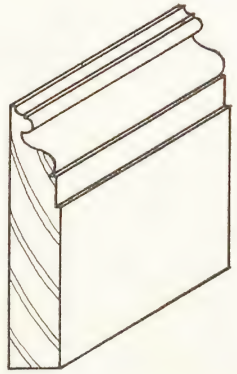
The simplest skirtings are the plain square board as Fig. 2, the splayed fillet as Fig. 3, quadrant Fig. 4, and scotia Fig. 5. Where the maximum floor space is desired, the flush, beaded skirting, which is flush with the plaster face, is useful (Fig. 6). Modern machinery now produces a large stock of skirtings of various sizes, moulded to divers sections, from the simple moulded top edge to the more elaborate double-face twice-moulded sections. Where necessity dictates that advantage shall be taken of every possible saving of cost, a suitable section from stock can usually be found amongst the more stereotyped designs, adapted from the old classic mouldings.

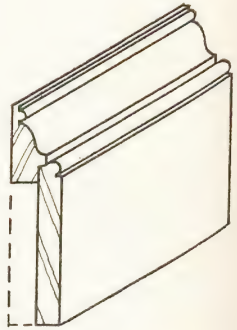


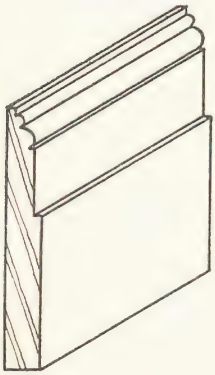
Period Styles

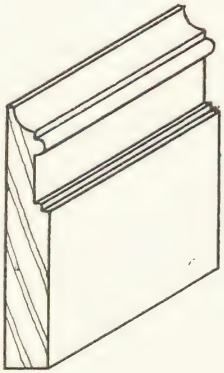
The design of the mouldings is a matter of the individual taste and skill in arrangement of the designer, combined with the effect it is desired to produce. Where it is required to follow a recognised "style" or "period," the profiles and arrangements distinguishing that "style" or "period," and differentiating it from another, must be studiously adopted. A few "period" skirtings are shown in Fig. 1.











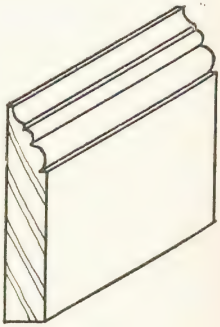


Fig. 1.—EXAMPLES OF SKIRTINGS USED IN VARIOUS ARCHITECTURAL PERIODS

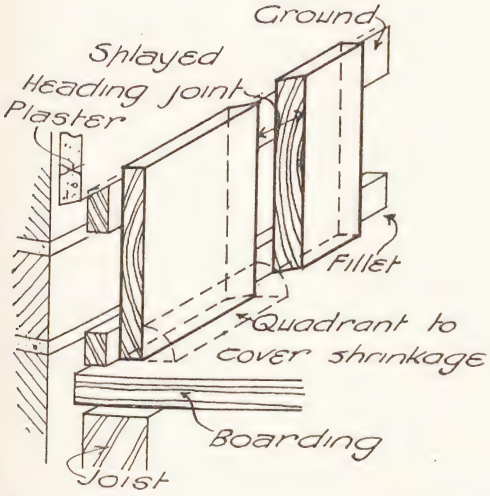


Fig. 2.—A TYPE OF PLAIN SKIRTING WITH GROUNDS

Plaster is not taken down behind skirtings in poor-quality work. Note the quadrant which is fixed to floor, which will hold bottom of skirting and will hide any shrinkage in it.

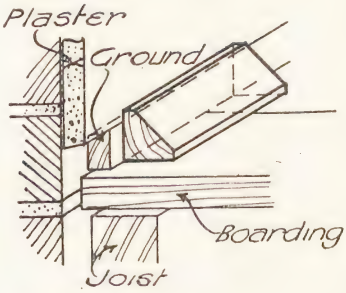


Fig. 3.—A SMALL SPLAYED FILLET USED AS A SKIRTING FIXED TO A SPLAYED GROUND

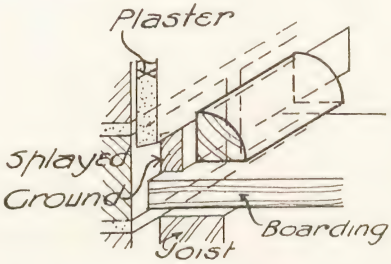


Fig. 4.—AN ORDINARY QUADRANT SKIRTING

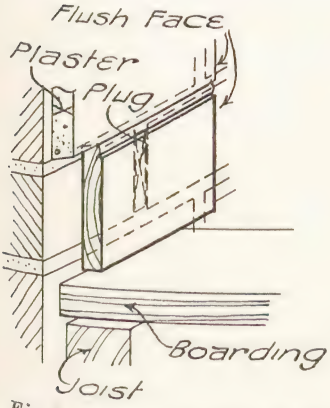


Fig. 6.—A SKIRTING FIXED FLUSH WITH PLASTER DIRECT TO WALL PLUGS

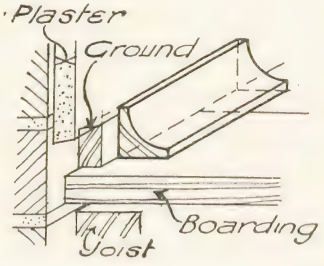


Fig. 5.—A SIMPLE SCOTIA SKIRTING WITH SINGLE SPLAYED GROUND

To Limit Marks of Floor Cleaning

A sinking, as shown in Fig. 7, or a groove, as in Fig. 8, about 2 in. from the bottom of the skirting, provides a definite line to limit or bound the inevitable marks of floor-cleaning operations.

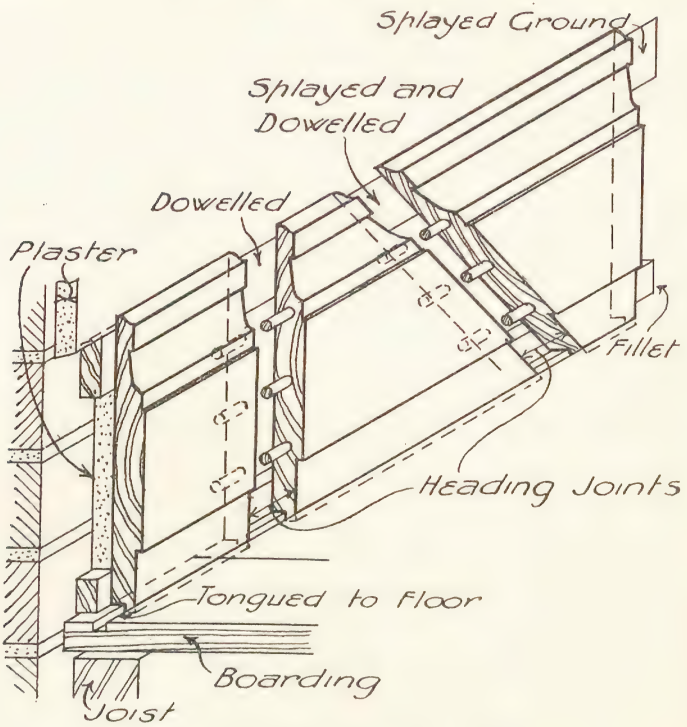


Fig. 7.—DOWELLED HEADING JOINTS

The skirting is fixed to grounds composed of splayed ground at top and fillet at bottom. Note how plaster is filled in between and to grounds, and also tongue of skirting grooved in floor to avoid cracks due to shrinkage.

Jointing with Other Joinery Fittings

Skirtings specially designed should be considered with the other joinery finishings of a room, such as the frieze and dado rails (if any), architraves, window boards, etc. The mouldings can be of the same contour to mitre with the architrave mouldings, as shown in Fig. 9, but where cost is relatively unimportant it is better to provide a "plinth block" to form a junction between the two, into which the skirting is "housed," as shown in Fig. 8.

Flush Cove

A flush cove inserted between the skirting and the flooring, as shown in Fig. 10, makes a first-class hygienic finish, and is especially suitable with polished floors; the polished surface should extend to the top of the cove. Where doorways occur the cove should be returned on itself at the outside edge of the architrave or architrave block, as shown in Fig. 10.

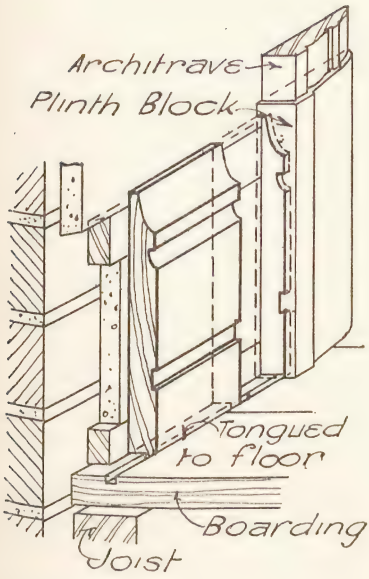


Fig. 8.—SKIRTING WITH A PLINTH BLOCK

Note the grounds and plaster behind the skirting. Also tongued and grooved joint to floor.

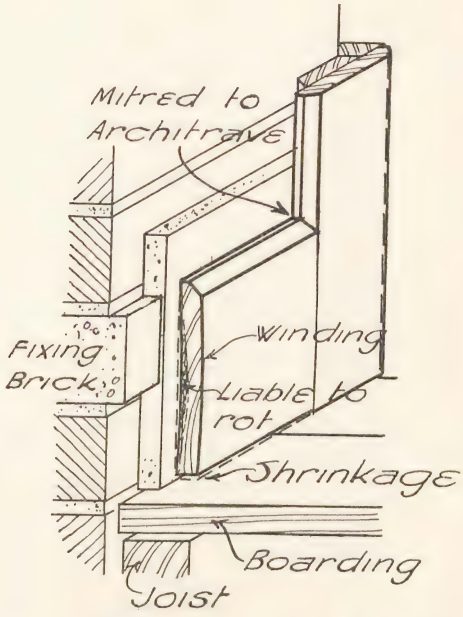


Fig. 9.—PLAIN SKIRTING FIXED TO BREEZE FIXING BRICKS

With plaster behind skirting. Note joint to architrave without plinth block, and also the dangers attending use of unseasoned wood.

Jointing Elaborate Skirtings

Elaborate skirtings are usually designed in two or three members tongued and grooved together, as shown in Fig. 11.

Avoiding Gap due to Shrinkage

Skirtings may have tongued bottom edges which project into a groove ploughed into the flooring, the object being that if any shrinkage takes place no unsightly gap will appear. As this entails cutting a groove across the grain of the boards at the ends of the room, it is confined to best work alone.

Methods of Fixing

The chief points to remember in the important work of correct fixing of skirtings are as follows :—

(1) To guard against fire.
(2) To guard against rot.
(3) To minimise shrinkage, winding, and splitting.
(4) Accurate jointing.

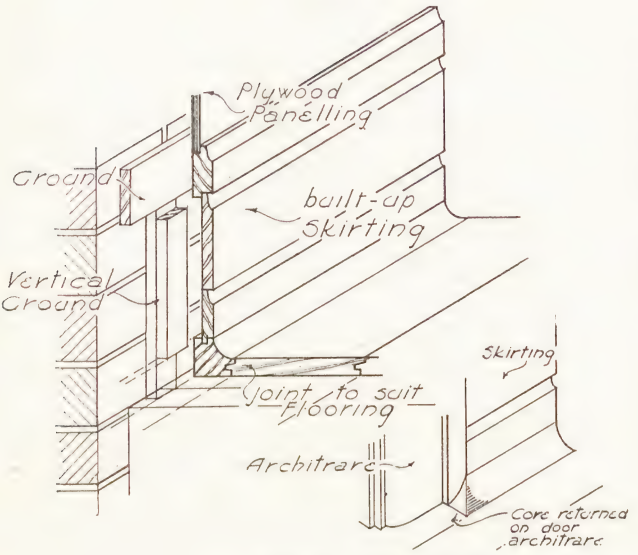


Fig. 10.—FLUSH COVE INSERTED BETWEEN SKIRTING AND FLOORING

The various methods to be explained are the outcome of long practical experience, rectifying past mistakes, and conform with standard practice.

Skirtings can be fixed either direct to wall or partition by nailing to breeze or wood fixing bricks specially built in, as shown in Fig. 9, or to grounds, backings, fillets, or "soldiers," which in turn must be nailed to plugs driven into the joints of the brickwork.

Plugs for Fixing

Plugs are slightly wedge-shaped pieces of yellow pine, preferably creosoted or otherwise protected from moisture, let into the vertical joints of brickwork about 18 in. apart at the required positions. They should penetrate about 3 in. into the wall and be the full height and thickness of the joint, which they should fit tightly. In order to do so they should be cross-grained to prevent shrinkage in their width, and subsequent loosening. Plugs should project slightly because of the irregularities of the brickwork. Plugs are indicated in Figs. 6, 11, 12, and 14.

Using "Soldier" Grounds

The most simple form of fixing for a skirting of any size is the use of upright grounds about 2 in. in width and $\frac{1}{2}$ in. less in height than the height of the skirting, and the same thickness as the plaster. These are spaced 1 ft. 6 in., 2 ft., or 2 ft. 6 in. apart, according to the thickness of the skirting. The plastering is usually carried down between the "soldiers" to the floor. Two "soldiers" adjacent to an external angle are shown in Fig. 12, with the intervening plaster omitted for clearness.

Possible Faults

There are two possible faults with this method of fixing. The first is a tendency to fix the "soldiers" too far apart. A good rule to remember

is that they should not be more than twenty-four times the nominal thickness of the skirting apart; this will apply in all cases, allowing a slight latitude to suit the spacing of the joints in brickwork, and consequently the plugs. The second fault is that the plasterer has nothing to screed his plaster against horizontally in the nature of a ground. He has, therefore, in order to make a true face for the skirting to butt against, to form a screed or fix a running-rule.

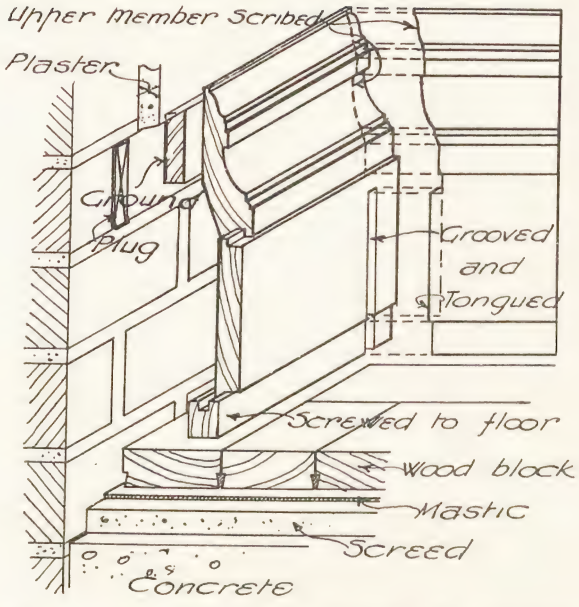


Fig. 11.—How internal angles of skirtings should be formed

Also how a skirting is fixed to wood-block flooring. This is a built-up skirting. Note the ground and plugs.

Single Grounds

Where the skirting is very narrow, such as a splayed fillet (Fig. 3) or a quadrant or scotia (Figs. 4 and 5), a single horizontal ground with splayed upper edge is all that is required. The ground is nailed to the plugs so that its lower edge rests on the boarding. The splayed edge forms a key to the plaster, and the ground itself forms the horizontal screed.

Double Grounds

For a wider skirting two grounds are required, the upper with its upper edge splayed as before, fixed about $\frac{1}{4}$ in. below the top of skirting, and the lower one, in this case called a fillet, fixed at the bottom. Examples of double grounds are shown in Figs. 2, 7, 8, and 13. In cases where the space between the upper

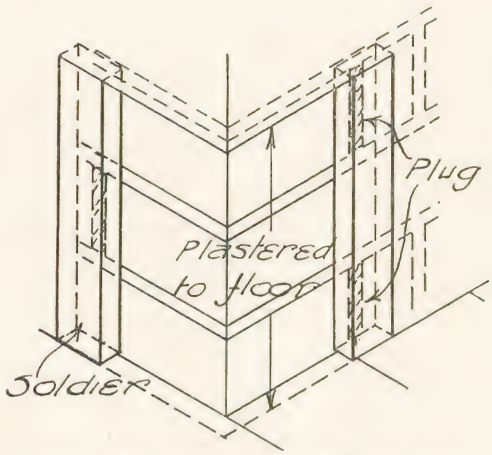


Fig. 12.—A simple "soldier" ground

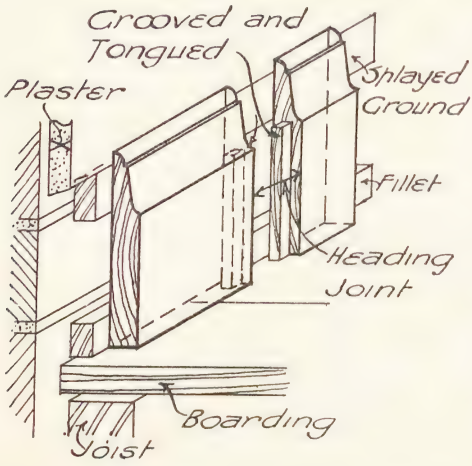


Fig. 13.—FIXING WITH DOUBLE GROUNDS
A moulded skirting with grounds and a grooved and tongued heading joint.

ground and the fillet is plastered, as shown in Figs. 7 and 8, the upper ground may be twice splayed.

Filling with Plaster behind Skirting—Advantage and Disadvantage

The reason put forward for this space to be filled in is because it provides a sound backing for the skirting, and prevents the harbouring of vermin and insects, but where the wood is not thoroughly seasoned the above reasons are more than discountenanced by the encouragement of the dry-rot fungus, which may be latent in the timber, by excluding the circulation of air. Fig. 9 depicts what may happen when unseasoned wood has been used. It shows dry rot, shrinkage, and bowing in one example, one, two, or even all of which defects may appear in due course.

Framed Grounds

For wide skirtings, and high-class work generally, the double grounds are framed together with dovetailed vertical members termed "backings," about the same size and distance apart as the "soldiers" previously described. An example is shown in Fig. 14. This renders the whole of the framework supporting the skirting rigid, in the event of a plug working loose. At external angles the upper splayed grounds should be dovetailed in order to facilitate the perfect mitring of the skirting at a point where it is specially noticeable.

Fixing Grounds adjacent to Flue

In order to comply with by-laws and fire office regulations, no timber of any sort must be fixed or inserted near a flue. Where a skirting abuts on to a fireplace surround of an upper floor, and against the side where a flue passes up from a fireplace below, the whole surface must be rendered between the grounds and the brickwork, as shown in Fig. 14. Wrought-iron wall hooks take the place of plugs in such positions, but care must be exercised to place them as far from the flue as practicable, to prevent their conducting heat to the timber. Wall hooks are shown in Fig. 14.

Methods of Nailing Skirtings

With the possible exception of quadrants, fillets, etc., where very little shrinkage can take place, it can be taken as a rule that skirtings must not be nailed to the floor. Theoretically they should be nailed only to the upper ground, assuming the skirting to have a tongue on lower edge free to shrink in groove ploughed in floor as shown in Figs. 7 and 8. The combined shrinkage of plates, joists, and boarding in one direction, and of the skirting itself in the other, should not be sufficient to lift the tongue out of the groove. In practice, however, the tongue and groove are usually omitted, for reasons already given.

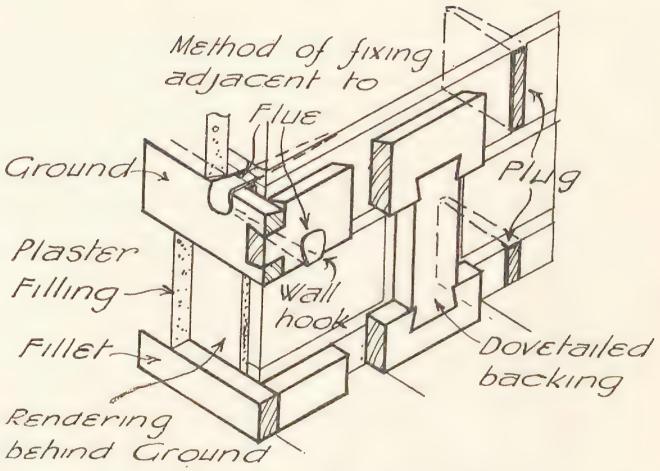


Fig. 14.—FIXING WITH FRAMED GROUNDS

Showing plugs for fixing grounds, method of forming angles of grounds, and method of fixing adjacent to flues.

There are two other methods that may be adopted. The first is to nail the skirting at a quarter or third of its height from the top, and to nail again at about the centre of the height, or a little below it. The distance between the nails will be too small for any possible shrinkage to draw past the nails, but will occur above and below them. This method is practicable where the skirting is fixed either direct to a breeze partition or fixing bricks, or to "soldiers," but it will be impossible to nail the centre of the skirting to double grounds, unless with backings.

The second method, which would be applicable to all cases, would be to "stagger" the nailing, that is, to drive each alternate nail near the top and bottom of skirting. Any shrinkage occurring will have the almost unnoticeable effect of causing the skirting to be wavy in its length.

GENERAL NOTES ON FIXING

Fix Wood Heart Side Outwards

Skirtings should always be fixed with the heart side outwards, so that any subsequent bowing will have the effect of binding the edges against the wall.

Quadrants and fillets may be nailed alternately to the splayed ground and to the floor, as little or no shrinkage can take place.

Where unseasoned wood has been used, but nailed at the top only, and an unsightly gap has appeared between the skirting and flooring, a small quadrant may be nailed to the floor to cover the gap, as shown by dotted lines in Fig. 2, but this is only a makeshift and is unsightly.

In Bedrooms

In bedrooms a piece of 4-in. by $\frac{1}{2}$-in. chamfered board (laid flat) is sometimes placed against the skirting to prevent the walls being damaged through the beds being placed too near.

Built-up Skirtings

Where elaborate skirtings are built up with more than one member, as shown in Fig. 11, the lowest member should be screwed to the floor, and all the members should be tongued and grooved together. Should a built-up skirting have considerable projection from the wall, it should have shaped backings at intervals, in addition to grounds.

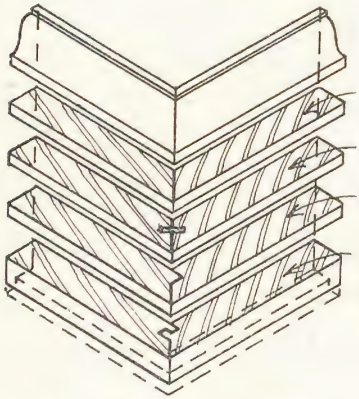


Fig. 15.—METHODS OF FORMING EXTERNAL ANGLES TO SKIRTINGS

Use of Grooved Fillet

In work of the best description, a grooved fillet, into which the tongue loosely fits, is sometimes screwed to wood-block floors to take all except the simplest skirtings, as shown in Fig. 11.

Where the skirting is not tongued to the floor it should be scribed.

JOINTS IN SKIRTINGS

Heading Joints

The ordinary and simplest method of joining a skirting, in its length, is to butt it, which in effect means that it is not joined at all, but that the length of one skirting simply bears, or butts, against the end of the other. This is not good, as the joint is almost bound to show in course of time.

An improvement is to splay the butt joint either vertically, as shown in Fig. 2, or diagonally, as shown in Fig. 7. In good-class work the joint is dowelled or splay-dowelled, as shown in Fig. 7, or the portion below the moulding may be grooved and tongued, as shown in Fig. 13.

External Angles

The junction of skirtings at external angles requires careful fitting. If the grounds are dovetailed at these positions, as shown in Fig. 14, the task will be easier. Fig. 15 depicts an external angle of a simple moulded skirting cut into horizontal sections in order to show the junctions in use. The mitre is, of course, the obvious joint for the position and is used in the large majority of cases. Its liability to open is counteracted a little by forming a rebate behind the mitre. For best work the grooved, tongued, and mitred, and loose tongued and mitred, joints are used, but their practical use is very much restricted.

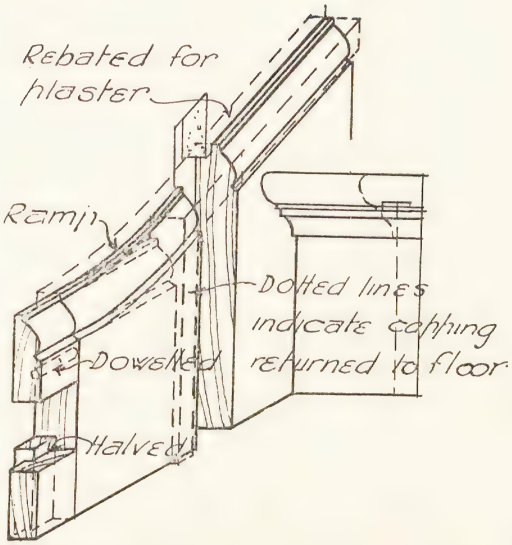


Fig. 16.—How skirtings should be joined to wall strings of stairs

The junction is treated as an ordinary heading joint, by butting, splay butting, halving, or dowelling. The latter two methods are shown above.

Internal Angles

The advantage of the internal or "re-entrant" angle is that the moulding may be neatly scribed to the adjacent piece carried through. This method, with the lower portion tongued, is the best way to deal with all internal angles, and is shown in Fig. 11.

Housing

Where skirtings abut against plinth blocks, wood fire surrounds, etc., they may be "housed," that is, the whole section let into the adjacent wood to the extent of about $\frac{1}{4}$ in. or $\frac{1}{2}$ in., and the latter cut out to the exact shape to

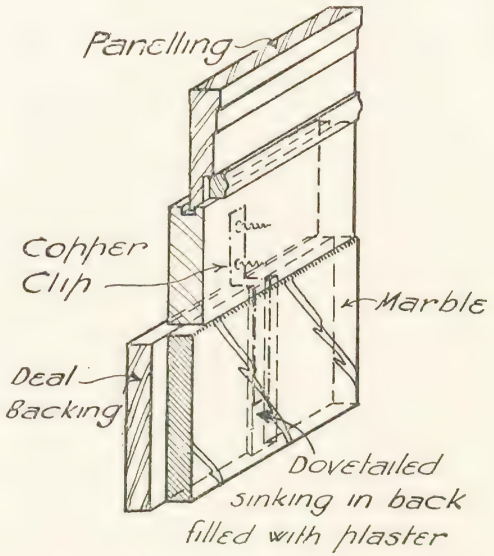


Fig. 17.—A composite skirting
Showing how the parts are fixed.

receive them. Fig. 8 shows an example of housing to a plinth block. In cases where the moulding on the upper edge of the skirting mitres with the architrave mould, as shown in Fig. 9, the lower part may be butted, or grooved and tongued similar to the heading joint depicted in Fig. 13.

Junction with Stair Strings

This is the most awkward problem connected with skirtings. Often the two are designed without any regard to their junction, and the result is what is known as a " botch." The best way is to treat the stair string as an apparent continuation of the skirting, the extra thickness of the string being rebated to take the plaster in line with the back of skirting, as shown in Fig. 16, and the string " ramped," that is, curved at its end to come into correct alignment with the skirting. The actual junction may then be treated as an ordinary heading joint.

In cases where, owing to the abnormal height of skirting or thickness of string, it is impossible to ramp the latter sufficiently for correct alignment, the following method is adopted. The string should have a capping with a square or splayed top, any moulding being on the front edge. This is mitred beyond the lowest tread nosing and returned and scribed to the floor, and the skirting is then butted or housed against its vertical face. The dotted lines on Fig. 16 indicate this method.

Fixing of Marble Skirting

Marble skirtings at bases of counters in shops, banks, etc., are becoming increasingly popular owing to their beauty and cleanliness. They require to be " secretly " fixed, that is, fixed from behind without any visible indication. It is usual to have a deal backing to frame up to the counter front above, so that the marble is merely a thin veneer sunk into the face. As the counter-front is usually in seasoned hardwood, little movement between its bottom edge and the marble is to be expected, and it is unusual to form any rebate or tongue. The method of fixing is depicted in Fig. 17. A dovetailed sinking is formed in the back of the marble at the required point, in which is embedded a copper clip in plaster of Paris; the other end of the clip is bent as required, and screwed to either the deal backing or the bottom rail of the panelling as shown.

MODERN CONSTRUCTION FOR FIRE PROTECTION

By H. Guy Holt, F.R.I.B.A., M.I.Struct.E.

MODERN fire protection may be divided into the constructional and extinctive aspects. It is proposed to deal with the constructional aspects in this article.

Types of Fireproof Construction

Modern fire-protective methods of construction appear to have been largely developed in connection with the construction of factories and warehouses involved in heavy fire risks. Such buildings as cotton and wool mills were constructed in the early days with cast-iron beams which carried brick arch floors, and at a later date wrought-iron joists were used to carry shorter-span arches filled in with concrete. Failures of this type of " fireproof construction," as it was called, proved the necessity for developing some better type of construction.

The increasing use of steel led to larger spans being used, and again these floors failed on account of the warping and twisting of the steel in fires, and the failure of the cast-iron columns supporting them, by fire or by the hoses of firemen causing fracture.

The necessity for protection of all steel members was evident. At the same time the increased use of concrete was making itself felt, and later on reinforced concrete was introduced.

Attention of manufacturers and builders having been thus drawn to the problems involved in designing and constructing a really " fireproof " building, much ingenuity and thought were devoted first of all to floor construction, and many systems were put on the market.

Among these a system known as " Whichcords " provided for the protection of the main beams of steel by means of fire-clay blocks.

In America and on the Continent the same problems were being tackled, and especially in America terra-cotta as a protection for steel began to be used. These terra-cotta tiles were of three kinds : dense, porous, and semi-porous.

The dense quality was proved a ghastly failure in the great San Francisco fire, and in a large fire at Pittsburg dense terra-cotta again failed disastrously.

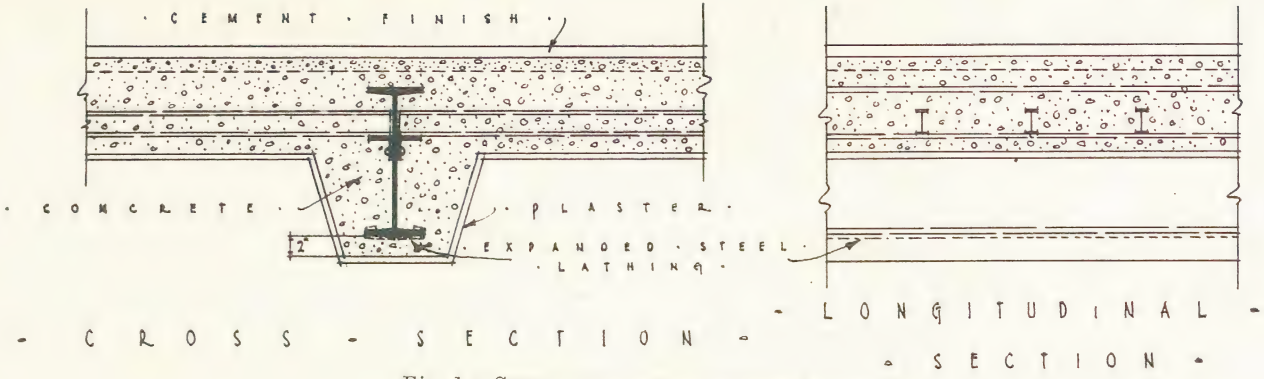


Fig. 1.—STEEL JOIST AND CONCRETE FLOOR

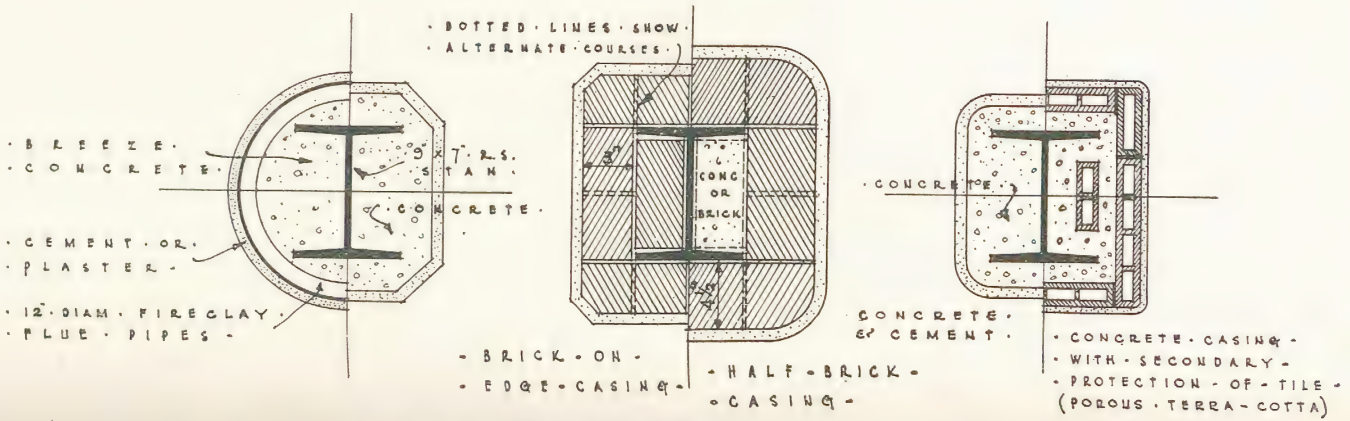


Fig. 2.—PROTECTION OF ROLLED-STEEL STANCHIONS

Modern Systems of Construction

Porous and semi-porous tile was then favoured, and to-day most high buildings of any importance in America are constructed with a steel frame and floors, protected by tiles of semi-porous or porous terra-cotta, as well as concrete. Terra-cotta is usually given preference because of speed in erection and quick drying. Reinforced concrete rapidly came to the fore and has been responsible for numerous types of floor, some of them of the precast type, being placed at the disposal of architects and engineers.

We find, therefore, that fire-resisting systems of construction nowadays may be classified as steel and concrete, reinforced concrete, steel and terra-cotta, or steel and precast concrete, either individually or combinations one with another, and the number of patent systems of construction is, of course, very large.

External Hazard Protection

It is necessary to have some acquaintance with the main principles involved in planning and constructing fire-resisting buildings.

External hazard is danger of fire from without, and in cases where the risk of fire is severe this becomes also the conflagration hazard.

In England, the Cripplegate fire of 1897 demonstrated this danger, and it is recognised by all fire insurance companies. Poor types of buildings, dangerous occupations, and even conditions of climates cannot be neglected. Protection against this may be summed up as brick or concrete walls, with protected openings as fire stop, and fire-resisting roofs.

Internal Hazard Protection

Internal hazard is the danger of fire spread from one part of a building to another, and is guarded against by fire-resisting floor construction, with openings protected against the vertical hazard, and fire-resisting walls and partitions, with openings protected against the horizontal hazard. Limitation of cubical contents is an important matter in considering internal hazard, and is provided for by legislation dealing with heights and cubical contents, in London by the Building Act (1894 and onwards) and similarly in other great cities.

Another important aspect of this matter is the view taken by the insurance companies under the tariffs framed by the Fire Offices Committee. These are numerous, and vary from time to time, but it is a great pity that there is not more co-ordination between public bodies forming building regulations and the Fire Offices Committee, with their wealth of practical information and experience.

The Protection of Openings

The protection of openings referred to is of the greatest importance in limiting the outbreak of fire, and this is accomplished by means of various

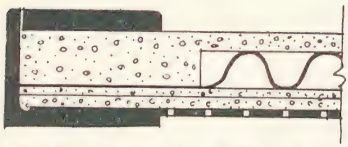


Fig. 3.—SECTION OF "CHECKFIRE" FIRE-RESISTING DOOR

types of fire-resisting door or shutter, where the opening is large, by fire-resisting glazing of the wired-glass or copperlite type in metal frames of windows, and by "drenchers," which will be referred to later. Most of these types must be approved by the local building authority, and, if the best insurance results are to be obtained, by the fire office.

Fire-resisting Glazing

Reveals of window and door openings facing a bad hazard should be deeply recessed where possible. Various methods of protecting exterior openings include fire-resisting glazing in hardwood or metal frames, the glass being not less than $\frac{1}{4}$ in. thick, and, if electro-copper glazing, the total size of squares should not exceed 400 sq. in. Wire mesh must not be larger than 1 in., and the glass fixed in the rebate at least $\frac{1}{4}$ in. A certain amount of heat passes through glass, and, of course, metal frames are preferable to wooden ones.

Fire-resisting Doors and Shutters

The disposition, fixing, and types of fire-resisting doors and shutters play an important part in protecting buildings from fire, and upon their efficiency very largely depends the success or otherwise of the general design of the fire-resisting arrangements to confine outbreaks. The question of heat radiation through these doors and shutters is most important, and should be practically nil, otherwise material on the side of the door away from the seat of fire may be set alight and so spread the fire internally throughout the building. Further, the door should be simple in operation, easily closed by automatic means in case of fire, and easily opened and shut during normal use.

Wooden Internal Doors

Internal doors, 2 in. full thickness, may be of wood under the London Building Act, and the 1905 Amendment Act mentions "oak, teak, jarrah, kauri, and other hard timber" as suitable. Actually such doors can only be classed as "slow burning," and whilst probably sufficient to retard fire long enough for the escape of occupants pending the arrival of the fire brigade, would be utterly useless if a serious fire got well under way. They are classed as temporary protection.

Metal-covered or Armoured Wood Doors

Metal-covered or armoured wood doors are much used, but are somewhat clumsy in appearance and handling, suitable for factory and similar work where appearance is not of great importance. Usually they are

constructed in $\frac{7}{8}$-in. boards laid diagonally at right angles to each other, and covered completely by sheets of tinned steel not less than 26 s.w.g. in thickness, and the sheets not exceeding 20 in. by 14 in. The sheets must be lock jointed, and allow for expansion and escape of gases. The defects of these doors are the possible escape of gases, from the boards, forcing open the joints of the tinned sheets sufficiently to allow the passage of flame, causing the collapse and failure of the door.

Iron or Steel Doors

Iron or steel doors are generally of $\frac{1}{4}$-in. mild steel, with top and bottom stiles, centre stile, and centre rail not less than 3 in. by $\frac{1}{4}$ in. with angle-iron frames, all riveted on. These doors tend to buckle during great heat, and depend for their ultimate efficiency very largely on the form of hinge and the fastenings adopted. Usually in fires they have stood in position, but become red hot, with considerable radiation, and water from a hose passes through the spaces where buckling has occurred. Composite doors of various types have been evolved by various manufacturers with success, and some of these are accepted by the Fire Office Committee. Generally the principle adopted is that of air insulation by a space in the central thickness of the door to prevent the passage of heat. These doors are generally a combination of steel, fine concrete, and asbestos.

Steel Rolling Shutters

Steel rolling shutters are employed where the openings to be protected are too large to be covered successfully by doors, and are used for internal and external openings. The most satisfactory type is that of the interlocking slat, and these are accepted by the L.C.C. and F.O.C. The slats take the form of continuous hinges one upon the other, forming a sheet which will revolve around a coil so as to make a complete fire-resisting joint and allow for expansion, the ends of the slats working in a steel guide fitted with stops to prevent the access of flame round the slat ends. Shutters must be designed to descend at a safe speed to avoid accidents.

Wrought-iron Shutters

Wrought-iron shutters are apt to buckle and radiate heat, and metal-covered wood shutters suffer from the same general defects as armoured doors.

Asbestos-cloth Blinds

Asbestos-cloth blinds, capable of use in the same manner as a spring blind, offer less radiation than the ordinary type of steel shutter, but are subject to considerable wear, and renewals at intervals are necessary.

Automatic Closing of Doors and Shutters

The automatic closing of doors, shutters, etc. in case of fire is of vital importance, and this is usually designed by means of a fusible link on a counterbalance weight, so that when fire occurs the link melts, releasing the weight and allowing the door to slide over the opening by means of pulleys running on an inclined bar. Employees in factories and warehouses are apt to wedge the doors open to save themselves the trouble of pulling the doors open when in use, so that the self-closing of these doors is apt to become an uncertain quantity unless strict supervision is enforced.

Single or Double Doors ?

Well-designed and constructed fire-resisting doors of normal size provide protection for about 1½ hours, after which time their behaviour is apt to become uncertain, and the arrangement of bolts, fastenings, and hinges is of great importance. Should the fire hazard be of a dangerous nature, double doors may be provided, one on either side of the opening in the wall, so that the air space between acts as a non-conductor ; the failure or partial failure of one door or shutter leaving the other ready.

Protecting Openings in Floors and Roofs

Openings to lifts, hoists, staircases, and wells, manholes, and trap-doors in floors and roofs should be protected in some form ; these are special points of danger, and need careful handling. Lift wells in the centre of staircases, though convenient and economical, are highly dangerous to the building unless protected, since they act as flues for the passage of smoke and flames from one floor to another, and have been the cause of many small fires developing into disastrous ones. Ventilating ducts, dumb-waiter shafts, ash and coal chutes, concealed roof spaces, and cupboards, floor and ceiling lights are all points of danger to be watched, and cut-offs corresponding with the compartmental division of the building should be arranged.

Staircases

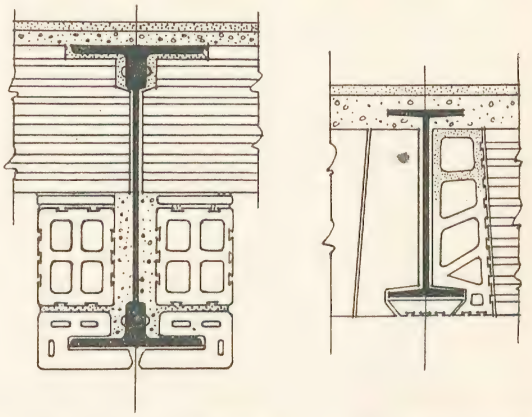
Staircases should, of course, be constructed of fire-resisting materials, and, where intended as possible means of escape, must be cut off from the remainder of the building by brick or concrete walls or fire-resisting partitions built from floor to ceiling.

In hazardous risks, such as textile mills, the staircases are arranged in a tower external to the rest of the building ; goods lifts and hoists, belt or shaft and conveyor openings should be protected by metal plates.

Unit Construction

Buildings in which dangerous occupations are carried on, or materials stored, such as explosive sheds, cotton stores, etc., are usually isolated

buildings. If this is not possible, solid, fire-resisting walls must be built to separate the special risk from remaining buildings, and any openings in such walls are limited in area and must be properly protected.



12-in. arch and casing for 24-in. plate girders, etc. 15-in. arch blocks for 15-in. I girders.

Fig. 4.—STEEL GIRDER PROTECTION

Protection of Steelwork

The evil results attending the non-protection of steel members of a building are now too well known to need further emphasis, but steel-protection is effected by various methods.

The protection of supporting columns is of vital importance: brick piers may be considered sufficiently fire-resisting in themselves; steel columns or stanchions and cast-iron or reinforced columns need protection, which can be afforded by concrete, brick and concrete, or terra-cotta. It is considered necessary to afford a minimum protection of 2 in. to main steel members in a building, and the soffits or under sides of all steel supporting members must be protected by concrete or terra-cotta so designed that it will withstand high temperatures without undue expansion and contraction, or spalling off under the action of high-pressure water jets.

Numerous tests on various materials and systems of construction have been carried out by the British Fire Prevention Committee and the F.O.C. in England, and the Underwriters' Bureau in America, and a great deal has been done to elucidate the causes of failure of certain methods, but lack of space forbids further mention of these tests.

Hollow tiles, fitted against steel members, are subject to severe strains, due to unequal expansion and contraction of the inner and outer surfaces in a fire, and on the application of water from a high-pressure hose fracture is almost bound to take place unless the webs are specially designed. Porous and semi-porous tile is greatly favoured in American city construction, because of the rapidity of fixing and drying; there is no waiting for large masses of concrete to dry out. The Woolworth and many other New York buildings have been protected by terra-cotta tiles, sometimes in combination with concrete.

Fire-resisting Reinforced-concrete Floor Construction

The development of reinforced concrete has been responsible for the introduction of numerous types of floor, some of the precast type.

Earlier efforts in reinforced concrete, particularly on the Continent, resulted in some failures, as nearly all new experimental systems must, and a certain distrust arose. "Structural" steel, as we know it—that is, stanchions, girders, and joists—with an "infilling" of concrete, has long formed a well-recognised floor in this country, and we may say that of late years there has been a tendency on the part of patentees and manufacturers to endeavour to combine the best of both types of construction—the terra-cotta and the concrete. The advocates of terra-cotta rightly point out that a material which has passed through intense heat in its manufacture is incapable of supporting combustion or being consumed by any ordinary fire. Concrete, they argue, has not passed through fire and is subject to various defects, due to the use of improper aggregate, poor grading and mixing; its proper application depends largely on intelligent design and supervision. All of this is true. The defects of terra-cotta have been indicated, and the possible defects of concrete construction are now sufficiently recognised and guarded against in good-class work.

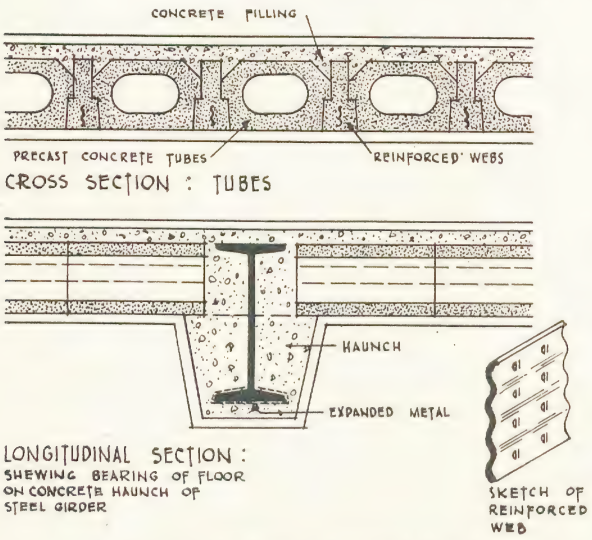


Fig. 5.—PRECAST CONCRETE FLOOR

We therefore find that fire-resisting types of floor and roof construction, column protection, etc., may be classified as terra-cotta, concrete, steel and concrete, reinforced concrete, and combinations of the foregoing. There are a number of cast-concrete floors in which timber centering or strutting is largely dispensed with. The number of patented flooring systems in use in this country, America, and the Continent is very large, but actually there are few *initial* types; most of the modern floors are improvements and adaptations in one form or another of the proved successful floor types of terra-cotta and concrete, and are generally combinations with sufficient variation in design to afford a fresh patent with "selling points," usually more true on paper than in reality.

Furniture and Contents of Buildings

By-laws in England now recognise the importance of fire-resisting construction, but whilst good construction ensures the resistance of the

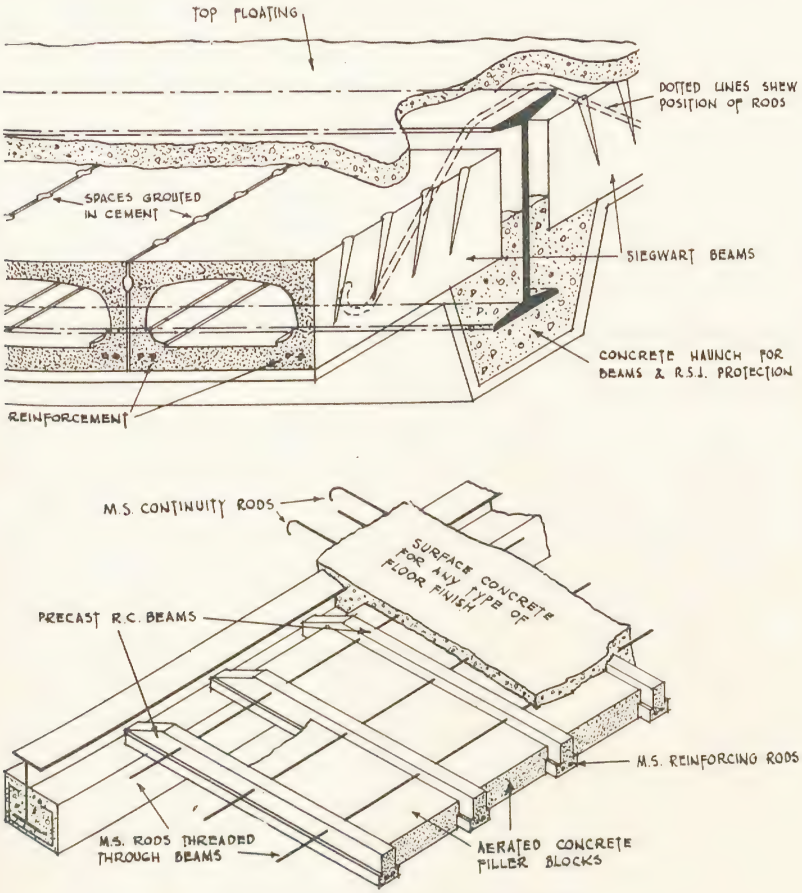


Fig. 6.—PRECAST CONCRETE FLOORS

building itself, the furniture and contents may be highly inflammable. For this reason the introduction of steel and other non-inflammable fittings has been developed in recent years.

Insurance companies do not pay the attention to constructional problems they should. Their main aim is to encourage fire appliances, and for these large rebates are allowed.

Once the fire has gained a hold, and extinctive apparatuses are found comparatively useless—particularly when water supplies fail, as so often happens—only the good construction of a building remains to withstand the risks of a conflagration commencing.

WOODEN-FRAMED WINDOWS

WINDOWS are one of the most essential parts of a building, of whatever character that building may be, and we purpose in this article to deal with the various types of wooden frames which are in constant use.

Any window opening, of whatever pattern, may be divided by mullions, or there may be a horizontal transom, or both mullions and transoms may be employed, as so commonly seen in the average bay window.

The Horizontal Sliding Sash

Perhaps the simplest form of a window frame is the solid frame with a sash sliding horizontally, sometimes called a " Yorkshire light." This is a very old-fashioned type, which may be seen in old cottages, and in later years has been employed on some municipal housing schemes. The frame has usually two or three sashes, only one of which slides. Fig. 1B shows the construction. It will be noticed that only the inner sash is movable. This frame has the advantages of simplicity and economy, as there are no expensive fittings, and the method of securing the opening sash can be simply a bolt to the cill. One of the disadvantages is that the groove in the cill, in order for the sash to slide, renders it difficult to keep out the rain, but this can be obviated to some extent by the use of a metal bar, which also will allow the sash to run more easily. Other disadvantages are the clumsiness of appearance, the liability of the sash to jam, and the difficulty of cleaning the outside.

Vertical Sliding Sashes

We naturally turn next to the well-known " sash windows," or vertical sliding sashes. This was a great feature of Georgian architecture, and is very typical of the period. During the nineteenth century scarcely any other type was employed. It is still used in many cases, though not greatly for domestic work unless the design of the building renders this style of window almost essential.

This window is the only one of the series we describe that is constructed with a boxed frame. The jambs are formed of two long shallow " boxes " (see Fig. 2), to enclose the weights which will balance the two sashes. Two shallow grooves are formed by the lining and beads, in which the sashes slide up and down. The long cast-iron weights inside the box are secured by hemp cords, which pass over wheels or pulleys fixed in a pulley stile, and are nailed to the sashes. Access to the weights,

Fig. 1.—"LUMEAH," CHURCH, SURREY. WEST FRONT

A design for which vertical sliding sash windows are suitable. The residence of a general practitioner, with separate entrance on the south side with a staircase leading to waiting-room on the first floor for panel patients. House built of multi-coloured local facing bricks with wide mortar joints. Woodwork externally painted cream. Roof of local brown hand-made tiles. (*Architect: W. J. Palmer-Jones, F.R.I.B.A.*)

Fig. 1A.—DESIGN WITH ARCHED SLIDING SASH WINDOWS

House of brick, with cream cement rendering, and reddish-brown pantile roof. (*Architect: C. J. Fawcett Martindale, F.R.I.B.A.*)

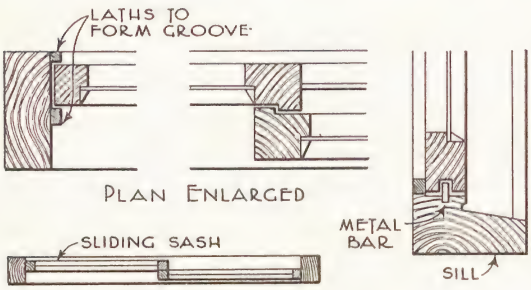


Fig. 1B.—HORIZONTAL SLIDING SASH

if required, is obtained by a "pocket piece" in the pulley stile. The cill is solid, and usually double-rebated; as in all windows, this is the danger-point, where rain is most likely to drive in.

The construction appears somewhat complex, but one great advantage is that the window can be opened slightly at the top, and give ventilation with less likelihood of draught than is probable with a casement, which must be open all the way down. Also, by using a very deep bead and bottom rail at the cill (Fig. 3), the bottom sash can be lifted and give a little ventilation between the two meeting rails, without the window being directly open at all.

There are, however, several disadvantages to this class of window:—

The sashes are very apt to jam, may be troublesome to open, more particularly the top sash.

Also, the sashes are very much inclined to rattle in a strong wind, so much so that small wedges have often to be used to silence them on a windy night.

Sooner or later the cords will wear out, two to three years being the average life of a cord. Then, rehanging of the sashes becomes necessary, a job that can only be undertaken by a competent workman. In better-class work chains are used instead of cords, and naturally last much longer.

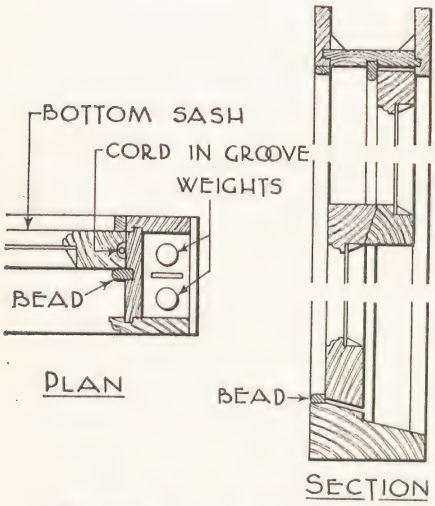


Fig. 2.—VERTICAL SLIDING SASH

The sashes, also, are difficult to clean externally.

In order to render the labour of opening less difficult, finger lifts should be screwed to the bottom rail of the lower sash, and it might be emphasised that, as a considerable strain will come upon the screws, there should be at least four to each finger lift. In some cases it is impossible for a person to lower the upper sash when he or she is standing on the floor, in which case a loop is screwed to the top rail, and the sash lowered and raised by means of a rod with a hook at the end.

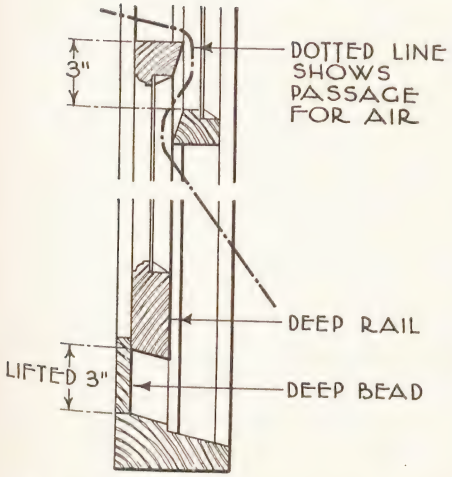


Fig. 3.—VERTICAL SLIDING SASH WITH DEEP RAIL

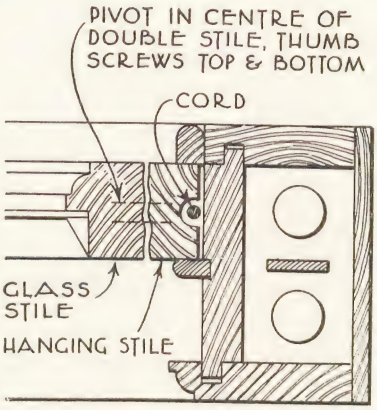


Fig. 4.—SASH WINDOW—DOUBLE-STILE PATTERN

It should be mentioned that in some of the cheaper work, only one sash (the bottom one) was made to slide, but generally this form of window was specified as "double hung." Also, in some of the eighteenth-century buildings the windows are divided by mullions. These mullions are naturally very wide, as each one has to contain the weights for four sashes. This, however, is somewhat uncommon.

Double-stile Sash Windows

At one period an ingenious variation of this window was on the market. The stiles of the sashes were made in two pieces: one, the sash or hanging stile, and the other the glass stile (Fig. 4). The slight grooves were intended to check the draught. The inner or glass stile was secured to the hanging stile by thumb-screws in cups, and with a pivot in the centre. On the screws being released the inner sash could be pivoted "inside out" for cleaning purposes. It must be noted that the double groove allows sufficient "play" for the inner sash to open. Otherwise, the construction is similar to the ordinary sash window.

Hopper Window

The next type of window to describe is the hopper. This is usually employed only as an upper or transom light. It is hinged at the bottom (Fig. 5), and falls inwards, generally opened by a rack opener and endless cord. If carelessly left open it is liable to let in the rain and wind; also, like all windows that open inwards, it interferes with the curtains, and the hanging cord is apt to be a nuisance. Rain and draught can be checked by providing fan-shaped glazed sides for the sash to fall back, but these

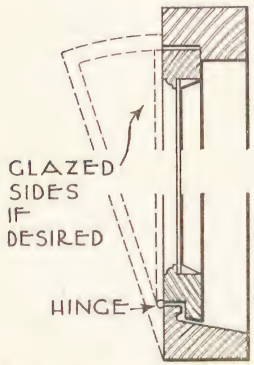


Fig. 5.—HOPPER WINDOW

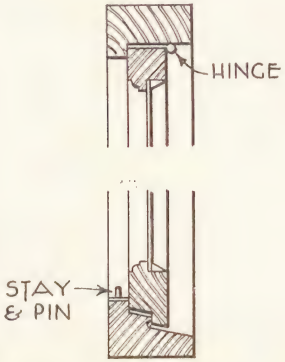


Fig. 6.—"PUSH-OUT" TRANSOM LIGHT

are very unsightly, and again there is the question of the curtains. Clearly, this is not a window suitable for domestic work.

The Push-out Transom Light

A better pattern for a transom light is one which, for want of a more suitable term, we may call a "push-out." Instead of being hinged at the bottom, as the last, it is hinged at the top, and is pushed out and secured by the ordinary casement stay (Fig. 6). It is a very simple type, but certainly can be used only as a transom light, and the transom must be low enough to allow easy reach for opening. There are special fittings to be obtained for opening this type, operated by a cord, which push the sash outwards. Should this sash be a wide one, two openers are required. This window has one great advantage—it can be safely opened during wet weather, a quality which most other windows lack.

The Side-hung Casement

There is little doubt that to-day the popular type of window is the side-hung casement. It is generally in a frame which is divided by mullions into two, three, or more lights, and with or without transom as the case may be. A point that may be discussed is: What should be the width of a casement sash? The standard size fixed by the manufacturers of steel frames is 20 in. over all, but the average builder, with his wooden sashes, usually makes them 24 in. to 26 in. It is probable that the width of 20 in. was fixed as being quite wide enough to pass the arm round for purposes of cleaning, and also a narrower width is less likely to be affected by the wind.

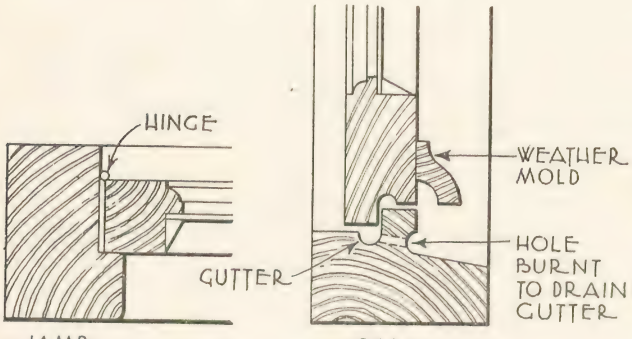


Fig. 7.—CASEMENT OPENING INWARDS

Casement Opening Inwards

A plan and section of the casement sash opening inwards are shown in Fig. 7. It is quite obvious that any form of sash opening inwards is more difficult to keep watertight than one opening outwards, as it is plain that, in the first case, any wind pressure has a tendency to push the sash open, whereas in the latter case the effect of the wind is simply to close the sash tighter. This pattern of window is rarely used, but where it is used, water should be kept out as shown in Fig. 7. Note the weather mould planted on the bottom rail, the rebate and groove in the cill. The latter should be of a generous width, to take any possible leakage, and should have holes at intervals to lead any water that may have collected in this small gutter to the outside. It might be emphasised that these holes should be charred after boring.

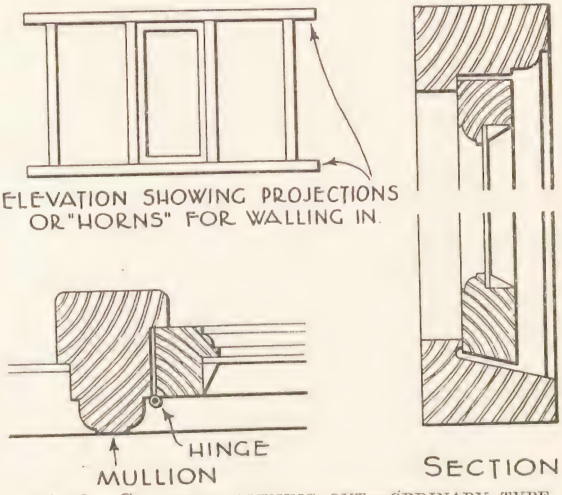


Fig. 8.—CASEMENT OPENING OUT—ORDINARY TYPE

Casement Opening Outwards

The casement opening outwards is possibly the most-favoured type of window to-day. It is quite obvious that the rebate, being placed in the opposite way to the last case, will better serve to keep out the weather. Fig. 8 shows the usual and most economical method of construction, but if a double rebate or sinking be made in the cill, and the grooves as shown in Fig. 9 are ploughed in both sashes and frame, it renders the whole window more watertight. It might be noted that the groove in the top rail of the sash should be slightly sloped so as to run the water off at each side. The main disadvantage of this type of window is the difficulty of cleaning, but if projecting hinges are used, the sash can be opened far enough back to allow the arm to pass between it and the frame. In a three-light window, as far as cleaning goes, only the centre light need open. It should be pointed out also that if the window is opened the stay-bar should be at once fixed, as the sash exposes quite a fair amount of surface to the wind, and a sudden gust might easily rip the sash off its hinges, or at any rate strain it.

Another objection to it is that it can rarely be opened without more or less draught, and also that in damp weather it is apt to swell, and if well

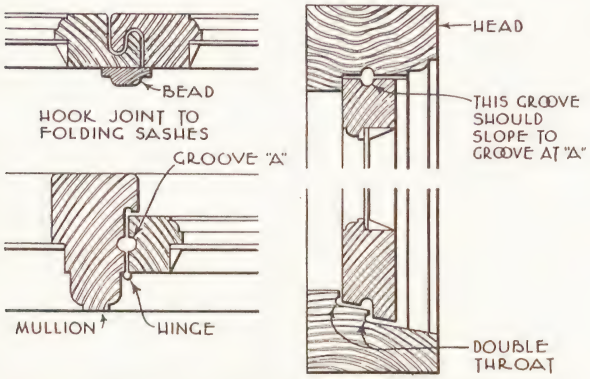


Fig. 9.—CASEMENT OPENING OUT—ANOTHER TYPE, SHOWING GROOVES

fitting be somewhat troublesome to open and close. This last remark, however, applies equally to all wooden frames.

In spite of all these objections, however, this form of window is probably the best for ordinary use.

Occasionally, casement sashes, whether outward or inward opening, are hung folding, that is, without a centre mullion, one sash being closed and bolted to the cill and head, and the other secured to it. In this case the "hook" joint, as shown in Fig. 9, is advisable, and a bead should be nailed to the sash last closed to cover the joint.

"Storm-proof"

As already mentioned, the most vulnerable point for weather in casement windows, or indeed in all types of window, is the cill. With a strong driving wind, heavy rain will stream down the window, and in spite of throating, grooves, drips, etc., the water will at times drive up under the sash.

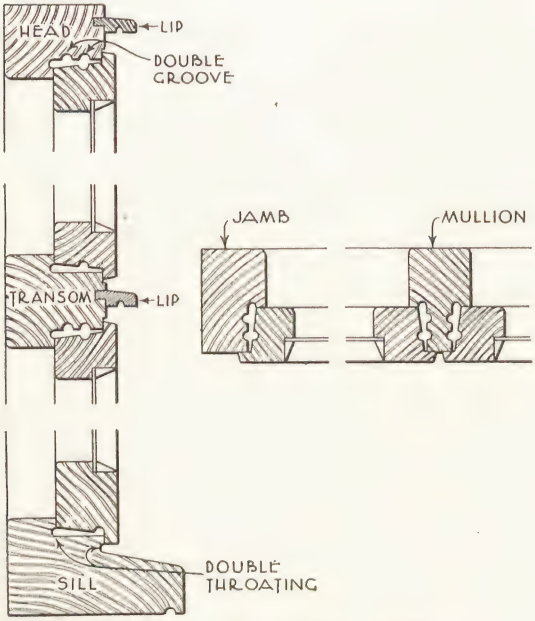


Fig. 10.—"STORM-PROOF" WINDOW

There are special forms of the casement window for preventing ingress of rainwater, such as the "Storm-proof." Fig. 10 shows this window with transom light. The series of grooves, to catch any water and stop its further progress, will at once be noticed. Note the following: the shield to prevent water from finding entrance; the double rebate in both frame and sash; $\frac{1}{8}$-in. clearance,

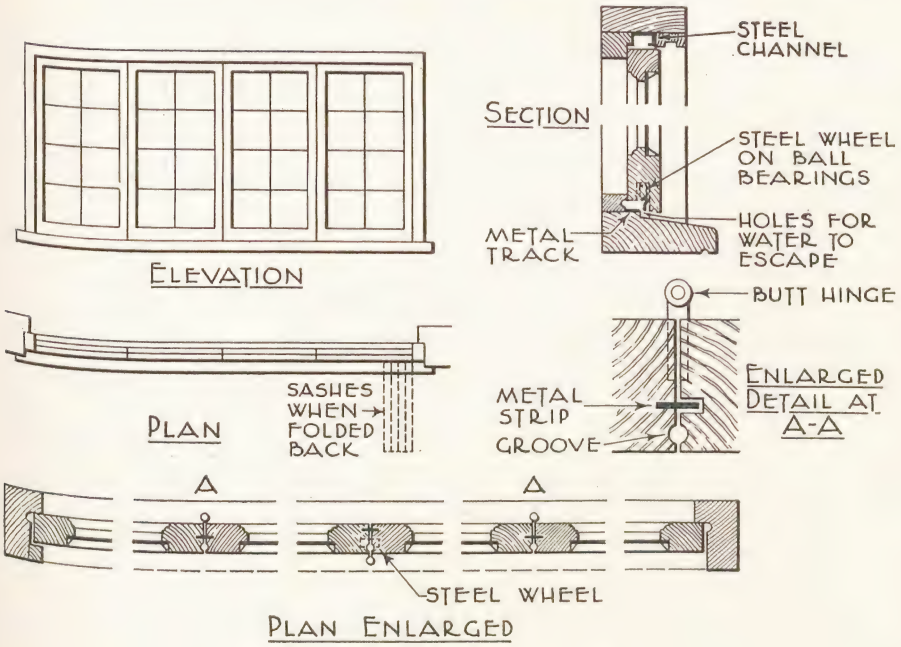


Fig. 11.—FOUR-LIGHT FOLDING SASH

so that sash will not bind with any swelling; and double throat in cill.

There are also other similar patents, such as "Ti-foon," which appear to be equally commendable.

Folding Sashes

The Educational Supply Association has patented a folding window, as Fig. 11, where the four sashes fold together, the sashes and centre upright sliding on a brass track on a wheel on ball-bearings, somewhat after the manner of the folding shutter. Though the drawing appears to be somewhat complex, the working of the window is very easy, and a large space can be thrown open to the air and sun. It should be noted that when fully opened the strain is not entirely on the hinges. Also another point is worthy of notice: the metal track which forms a gutter to catch the water that may be driven in is pierced with holes to allow the water to escape.

Centre-pivot Sash

Another class of useful window as a top light is the centre-pivot sash. This sash simply works on a couple of centre pivots, fixed horizontally, and if high up is usually opened by means of a cord. The rebate is formed by a double bead, part nailed on frame and part on sash.

Vertical-pivot Sash

The vertical-pivot sash is occasionally employed (Fig. 12). Here, as the term implies, the window sash is fixed on two pivots top and bottom. It is not a common type, but is found at times in the upper storeys of factories.

In the illustration given, it should be noted how part of the bead, on both outside and inside, is nailed to the frame, and the continuing portion to the sash, thus preserving the appearance, but frankly, the section of the cill does not appear to be absolutely weathertight.

The main advantage of pivot-hung windows, whether vertical or horizontal, is ease and convenience in cleaning.

The Sash Bars

All these various types of sash may be divided by sash bars. In nearly all these division bars, the rebate and the putty are outside, though a better but unfortunately more expensive method is to have the rebates inside, and to fix the glass with wooden beads.

Reveal or Flush Fixing?

The window frame may be fixed flush or nearly so with the external face of the wall, or the usual method of allowing a 4½-in. external reveal may be followed. Each method has its advantages, the first mentioned allowing a broad internal window cill, but the last named is generally considered as the more watertight one. If the two sections in Fig. 13 be studied, it will be observed that in the ordinary method, water running down the face of the wall will find it more difficult to penetrate at the window head. If the check or recess of the brickwork be observed, and the frame be flush, water can trickle over the head and down inside the frame, whereas, in the case of an external reveal, the check of the brickwork will interfere with this. If it is specially desired to fix the frame flush, a course of tiles as a drip above the frame is desirable (Fig. 14). Unfortu-

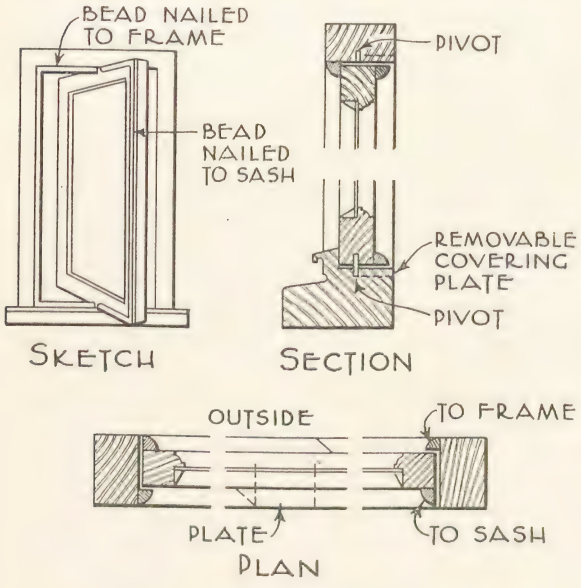


Fig. 12.—VERTICAL PIVOTTED SASH

Fig. 12A.—HOUSE NEAR MARLOW, BUCKS

A long, low house with wooden side-hung casement window treatment. Built of multi-coloured bricks and hand-made sand-faced tiles. (*Architect: G. Berkeley Wills, M.C., F.R.I.B.A.*)

Fig. 12B.—"WEST END," FRENSHAM, SURREY

The above house was once an ugly Victorian red brick villa. The picture shows the result of conversion. Note the sliding sash windows. Local red facing bricks are used. Low-pitched roofs of Cornish slate. Columns to portico, cornice, etc., are of deal, painted cream. (*Architect: W. J. Palmer-Jones, F.R.I.B.A.*)

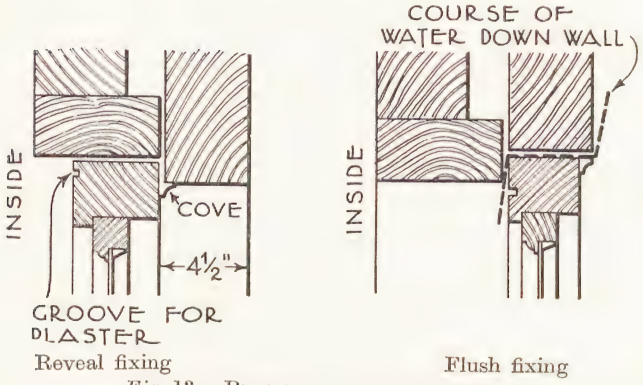


Fig. 13.—REVEAL AND FLUSH FIXING

nately, these are rather brittle and very likely to crack, and certainly could not be used with a boxed frame. Another point in favour of fixing the window frame in reveal is that there is more space available for the curtain brackets, which, if a frame is fixed flush, is likely to be considerably reduced (Fig. 14), unless exceptionally heavy frames be used.

When to Fix the Frames in Building

Another matter often discussed is whether the frames should be built in as the work proceeds, or whether the openings should be left in the brickwork and the frames fixed afterwards. The former method is considered by many to be the better: it is argued that the frames will be firmer and the heads and cills can be about 3 in. longer each side (see Fig. 8), thus giving a firmer grip in the wall.

Finish Externally and Internally

All frames are pointed to the brickwork externally, but this pointing has an unpleasant habit of dropping out. If a bead or cove mould be sprigged to the frame (Fig. 13), after pointing, this is impossible. With regard to the internal reveal, whether this be finished with plaster or a wood lining, the frame should be ploughed or grooved to receive the desired finish.

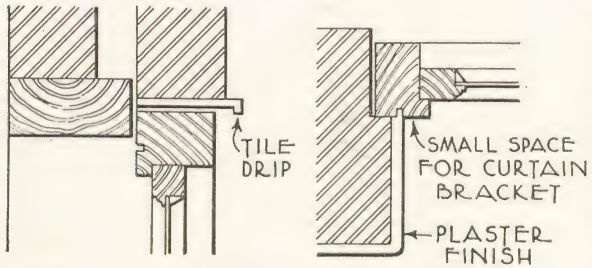


Fig. 14.—TILE DRIP FOR FLUSH WINDOW FIXING

Metal windows are largely used in the building trade, but it is improbable that the demand for wood frames will die out. Several firms in this country make a speciality of these.

SELECTION OF WOOD JOISTS

THE timber available for joists is usually in stock sizes, but it often means a considerable saving in cost to calculate the exact size required, and the design of common joists is not a difficult matter to anyone able to work simple arithmetical problems. The following is intended for those having little knowledge of mechanics and mathematics, and is arranged so that the reader may utilise the practical information without studying the theory of the subject. Hence, the use of the formulæ is considered first, and the explanation given later.

The Formula for Strength

The two things to consider are (1) the effect of the loads on the joist, and (2) the strength of the joist to resist the loads. The former is called the *bending moment*, and the latter the *moment of resistance*. The two values are always equal, i.e. bending moment = moment of resistance. Therefore the formula for the strength of a beam is BM = MR, which is often abbreviated to M = R.

Bending Moment

In many cases the bending moment is troublesome to obtain, but for common joists, under ordinary conditions, resting on two walls, it is always $\frac{1}{8}$WL, where W is the total load on the joist (including its own weight), and L is the length, or span, in inches. Therefore we will use this value while we consider the selection of the joist, and consider special cases later.

Span of Joist

The length, or span, to consider in the calculations is called the effective span, and is greater than the clear span, or the distance between the walls. The effective span is measured from the centres of the bearings ; therefore, if the joist rests 4 in. on each wall and the clear span is 9 ft. 8 in., then the effective span is 10 ft. (see Fig. 1).

Load on Floor

Before a joist can be designed it is necessary to know what load is to be allowed on the whole floor. The usual practice is to consider the load in pounds per square foot ; and this load varies with the type of building

and the purpose for which the floor is intended. The load may vary from 40 lb. per square foot for the bedroom of an hotel, to 200 lb. per square foot for a warehouse, or even more for special cases. The following Table shows the loads usually adopted in practice, and those suggested by the L.C.C. Code of Practice. They are specially applicable to steel-framed buildings.

SUPERIMPOSED LOADS FOR FLOORS AS EQUIVALENT DEAD LOADS

Type of Building	*Usual Allowance*	*L.C.C. Code of Practice*
	Lb. per ft. sup.	*Lb. per ft. sup.*
Domestic buildings, hospital wards, hotel bedrooms	50	40
Offices, floors above entrance floor	60	50
Offices, entrance and lower floors	80	80
Schoolrooms, reading-rooms, art galleries, etc.	80	70
Retail shops, churches, garages for light vehicles (under 2 tons)	80	80
Light workshops, cinemas, assembly and dance halls, landings and stairs	100	100
Warehouses, book stores, garages for heavy vehicles	200 upwards.	Loads to be calculated.
Flat roofs, up to 20° inclination	40	30

Load on Joist

The above loads are for the whole floor, and are given for the purpose of designing the supports for the joists and not for the joists themselves. It is usually the case that one joist will carry far more load than another in actual practice. Hence it is usual to adopt a value of 70 lb. per square foot for the load when designing a joist, an increase of 40 per cent.; and experience proves that if the joists are designed for smaller loads they will not be sufficiently rigid against deflection, as will be seen later.

Weight of Joist and Ceiling

It is necessary to adopt an approximate value for the weight of the joist, floorboards, and ceiling. So we decide on what we think will be the size of the joist, say 8 in. by 2 in. Then the volume of the joist is, say, 10 ft. by 8 in. by 2 in. = 1·1 cu. ft. The amount of flooring carried by the joist is equal to the spacing of the joists multiplied by the length of the joist (see Fig. 2). Hence the volume of the flooring is, say, 10 ft. by 1 ft. 3 in. by 1 in. = 1 cu. ft. Therefore the total volume is about 2 cu. ft., and the average weight of redwood joists and whitewood floorboards is, say, 32 lb. per cubic foot, ∴ the weight is 64 lb. This weight need not be calculated accurately, as it is only a small fraction of the total load. Lime plaster weighs about 120 lb./cu. ft., ∴ weight of ceiling carried by joist = $\frac{3}{4}$ in. × $\frac{1}{12}$ × $1\frac{1}{4}$ ft. × 10 ft. × 120 lb. = say 100 lb.

Approximate Weights

A rough estimate, sufficiently accurate for ordinary purposes, is to add 10 per cent. to the superimposed load for unceiled floors, and 20 per cent. for ceiled floors. Therefore, if the superimposed load allowed on the joist is 70 lb., the total dead load is 77 lb., or 84 lb. per foot super.

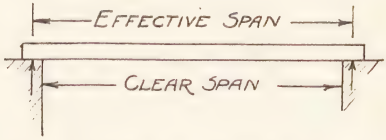


Fig. 1.—SHOWING DIFFERENCE BETWEEN CLEAR AND EFFECTIVE SPANS

Spacing of Joists

The next consideration is the spacing of the joists, which is usually between 14-in. and 16-in. centres. If the joists are spaced 15 in. from centre to centre, or in-to-out, as shown in Fig. 2, then each joist will carry 15 in. of floor surface for the span of the joist. Therefore the load on each joist will be span $\times$ 1 ft. 3 in. $\times$ load per foot super. Assuming a joist of 10-ft. span, and a total load per foot super of 84 lb., then the load will be 10 ft. $\times$ 1 ft. 3 in. $\times$ 84 lb. = 1,050 lb.

Bending Moment

Therefore the bending moment is 1,050 lb. $\times$ 120 in. $\div$ 8 = 15,750 lb. in. As pounds and inches were used in the calculation the answer is in compound units, or lb. in.

Moment of Resistance

We will now consider the resistance of the beam, MR, which is the other side of the equation. This is always $\frac{fbd^2}{6}$ for a rectangular section, where f is a value denoting the strength of the wood per square inch of section, b is the thickness, and d the depth of the joist.

Strength of Timber

There is considerable variation in the strength of different timbers, even in different pieces of the same kind, and it is necessary to know the strength of the particular wood to be used. This is provided for us by experts, who conduct numerous experiments with different qualities of the particular wood until they can say with confidence what the *average* strength is, according to their experience. Timber is a very

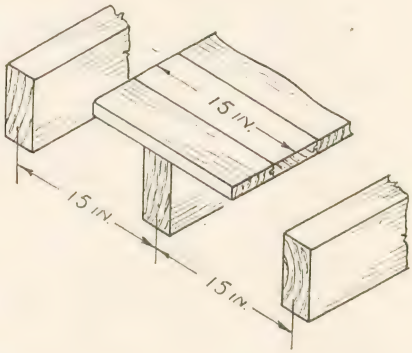


Fig. 2.—AREA OF FLOOR CARRIED BY JOIST

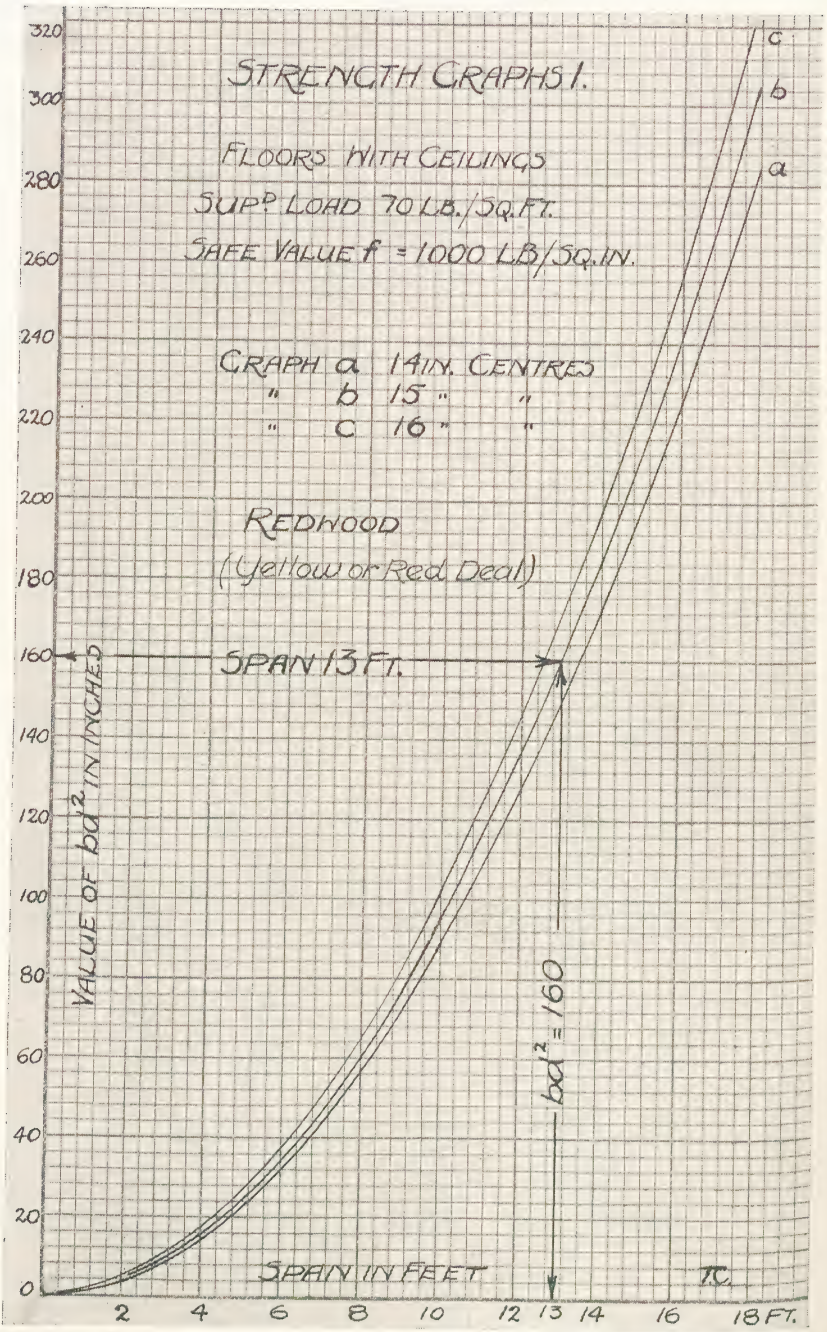


Plate I.—Graphs showing the sectional areas of joists for given spans for such timbers as yellow deal, Scots pine, etc. These graphs are for floors with plaster ceilings

uncertain material, but we must accept the values provided for us, which are dependable for straight-grained seasoned wood of average quality.

Factor of Safety

The strengths of the different woods are obtained by breaking numerous specimens, and the value of f is obtained in this way. We have now to decide on a *safe* value from this *breaking* value. For instance, if we know that when $f = 6{,}000$ lb. Baltic fir will break, we decide to use, say, a safe value of f of $6{,}000 \div 6$, or 1,000 lb. This is called using a factor of safety, FS. In this case we adopted a value of 6 for the FS, which experience suggests is the minimum value that should be used for permanent work. The safety factor is used also to allow for various other contingencies, such as indiscriminate cutting of the joist, unexpected loads, deterioration of the wood with age, and defects such as wane, twisted grain, knots, etc. It is a question for the designer to decide on the safety factor, and many use 7 or 8, and even 10 for permanent structures to withstand severe conditions. At the same time we may go as low as 3 or 4 for temporary work. Another point to keep in mind is that seasoned wood is much stronger than unseasoned.

Applying the Formula

We will now apply the formula to a particular case. It is important to notice that the same units must be used throughout, and in the examples the unit of weight is the pound and the unit of length the inch.

Example.—Design a redwood joist of 10-ft. effective span for a superimposed load of 70 lb. per foot super, to carry a plaster ceiling.

$$\text{BM} = \text{MR} \quad \text{or} \quad \frac{\text{WL}}{8} = \frac{fbd^2}{6}$$

In this case we require b and d. Therefore, transpose f and 6 to the other side of the equation, then $\frac{\text{WL} \times 6}{8 \times f} = bd^2$. We have calculated the value of W, which is 1,050 lb., and $f = 1{,}000$ lb., $\therefore \frac{1050 \times 120 \times 6}{8 \times 1000} = 94{\cdot}5$. Assuming the joist to be 2 in. thick, then $d^2 = 47{\cdot}25$, $\therefore d = \sqrt{48}$, which is nearly 7 in.

Therefore a 7-in. by 2-in. joist would be strong enough for the example, but it may not be sufficiently rigid.

Deflection

The next consideration is the deflection of the joist, which depends upon the stiffness. If it bends, or sags, above a certain amount when loaded, the ceilings will crack and the floor will creak. The maximum amount of bending is again decided for us. It should not be more than

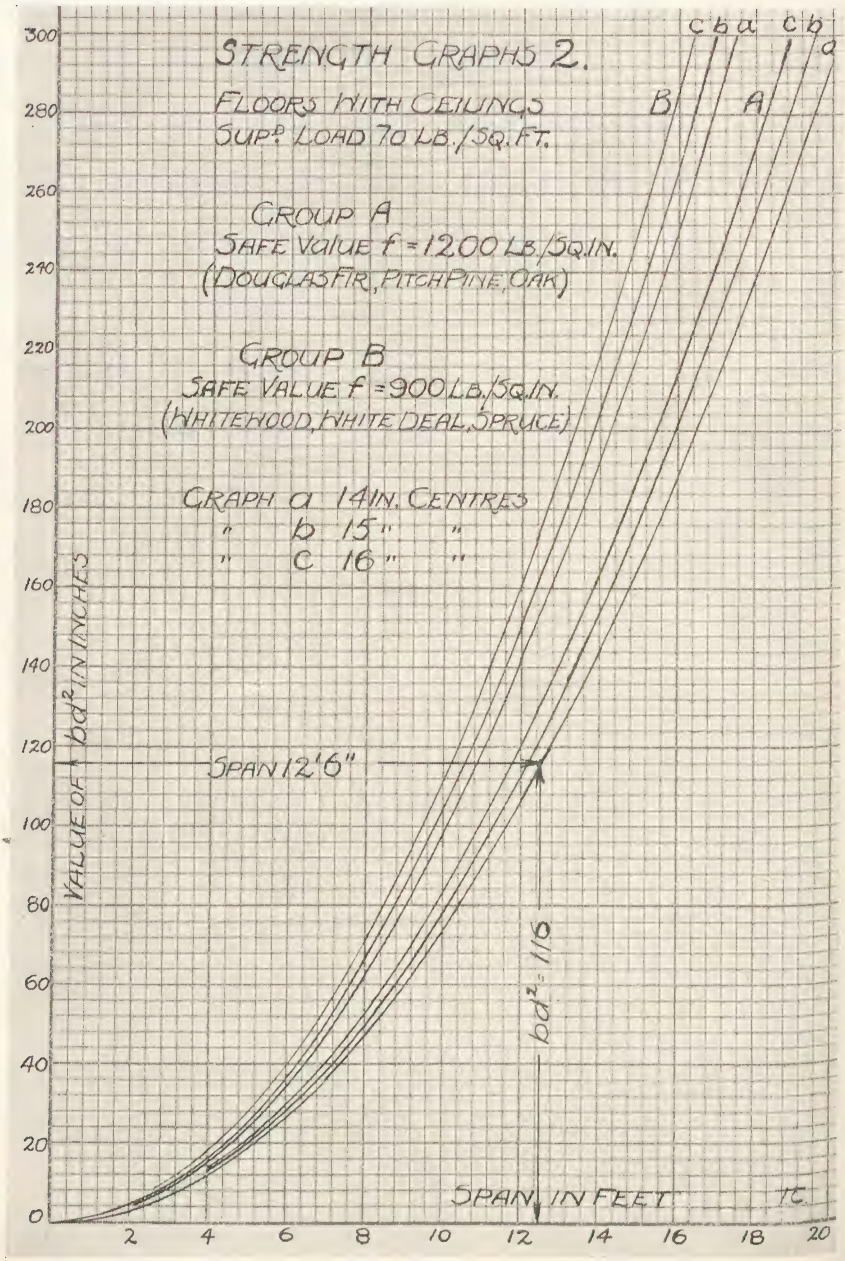


Plate II.—GRAPHS SHOWING THE SECTIONAL AREAS OF JOISTS OF BALTIC FIR, SPRUCE, ETC., AND DOUGLAS FIR, PITCH PINE, OAK, ETC. THESE GRAPHS ARE FOR FLOORS WITH PLASTER CEILINGS

$\frac{1}{10}$ in. per foot of span, or $\frac{1}{480}$ of span. Some authorities allow $\frac{1}{1000}$ of the span. If there is no plaster ceiling the maximum deflection is usually taken as $\frac{1}{360}$ in. per foot of span.

The Formula for Deflection

Unfortunately, the formula this time is more complicated. If the reader, however, only considers the arithmetic and ignores the significance of the symbols he will have no difficulty in finding the deflection of a joist. The symbols will be explained later.

The formula is : Deflection $= \frac{cWL^3}{EI}$, where W is the total load on the joist, L is the span of the joist, and c is a constant that depends upon the kind of loading and fixing, but for ordinary joists is always $\frac{5}{384}$. The symbol E is a value depending upon the kind of wood, and represents the property of the material to recover itself after the load is removed, and is about $1\frac{1}{4}$ million, using units of pounds and inches. It is called *Young's modulus*, or the modulus of elasticity. I is the *moment of inertia*, and is a value that depends upon the size and shape of the section of the joist and the disposition of its parts about an axis. For a rectangular section, like a wood joist, it is always $\frac{bd^3}{12}$. It is important that the same units be used throughout, and in these calculations pounds and inches are used.

Applying the Formula

If the allowable deflection is $\frac{1}{480}$ of the span, then :—

$$\frac{\text{span}}{480} = \frac{5 \times W \times L^3}{384 \times E \times I}$$

Applying this to the 10-ft. joist already designed for strength :—

$$\frac{120}{480} = \frac{5 \times 1050 \times 120 \times 120 \times 120}{384 \times 1200000 \times \frac{bd^3}{12}}$$

To find the value of b and d, cancel the fraction as far as convenient and rearrange the equation :—

$$\therefore \frac{1}{4} = \frac{5 \times 105 \times 3 \times 3}{2 \times 10 \times bd^3}$$

$$\therefore bd^3 = \frac{5 \times 105 \times 9 \times 4}{2 \times 10}$$

$$\therefore bd^3 = 945.$$

But $b = 2$ in., $\therefore d^3 = \frac{945}{2} = 472{\cdot}5$, $\therefore d = \sqrt[3]{472{\cdot}5} = 7{\cdot}79$ in. Therefore a joist 8 in. by 2 in. is required. We cannot use less than 2 in. thick

because of nailing and jointing the floorboards, although it is stronger than is necessary.

The reader may have difficulty in extracting the cube root to obtain d, but as the joists are of stock sizes it may be obtained by trial. For instance, $7 \times 7 \times 7 = 343$, which is too small, and $8 \times 8 \times 8 = 512$, which is only slightly above the required value.

Bridging and Strutting

Deflection should always be considered when selecting the sectional area of the joist, as it is a guide in choosing the depth. We can select the thickness to suit the strength requirement. If the deflection suggests deep slender joists, it is necessary to use bridging or strutting to prevent them from canting, bowing, warping, etc. The bridging or strutting should be at intervals of not more than 6 ft. 6 in., and by-laws usually demand this. When the joists are well strutted the superimposed load need not be considered so large when designing against deflection. The strutting, flooring, and ceiling all tend to spread the deflection over a greater area than a single joist.

Shear

There is another consideration in the design of structural members, and that is the resistance against shear. It is seldom necessary to consider this in the design of common joists, because if the joist is satisfactory for strength and stiffness it is practically always of sufficient size to resist shear. It is advisable to test the joist, however, when the sizes have been selected. The formula is $S_B = \frac{3}{2} \times \frac{S}{bd}$, where S_B is the bending shear, and S is the maximum shear force acting on the beam. For common joists, $S = \frac{1}{2}$ total load $= \frac{1}{2}W$.

Therefore, for the 8-in. by 2-in. joist for 10-ft. span, which carried a total load of 1,050 lb., $S_B = \frac{3 \times 525}{2 \times 2 \times 8} = 49$ lb./sq. in. The safe value given in the following table for redwood is 100 lb./sq. in., therefore the resistance against shear is quite satisfactory.

TABLE OF SAFE WORKING VALUES
IN POUNDS PER SQUARE INCH

Timber	*f*	*Bending Shear*	*E*
Whitewood (white deal) . . .	900	80	1,200,000
Spruce	900	80	1,200,000
Redwood (yellow deal, Scots pine) .	1,000	100	1,200,000
Douglas fir	1,200	110	1,500,000
Pitch pine	1,200	120	1,500,000
Oak	1,200	130	1,200,000

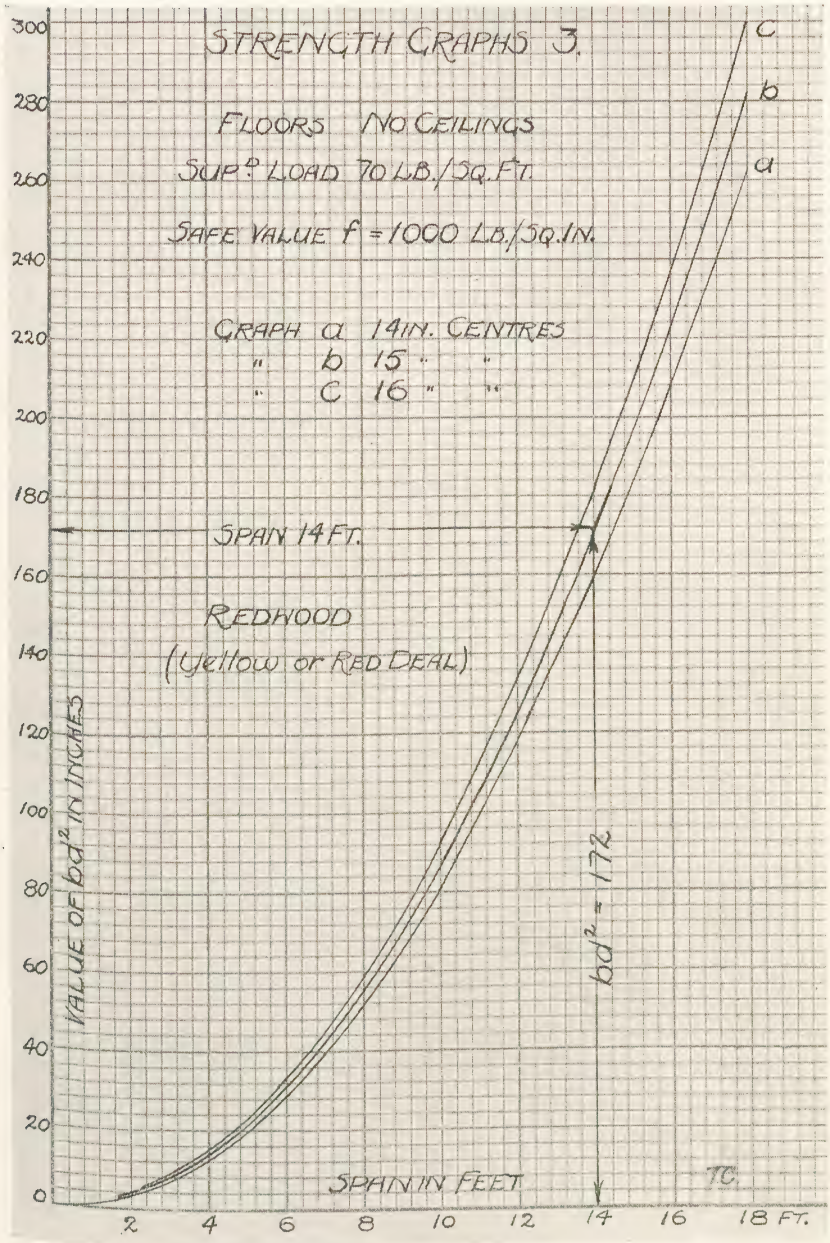


Plate III.—GRAPHS SHOWING THE SECTIONAL AREAS OF JOISTS FOR YELLOW DEAL, SCOTS PINE, ETC., FOR FLOORS WITHOUT CEILINGS, OR WITH LIGHT CEILINGS OF CEILING-BOARDS

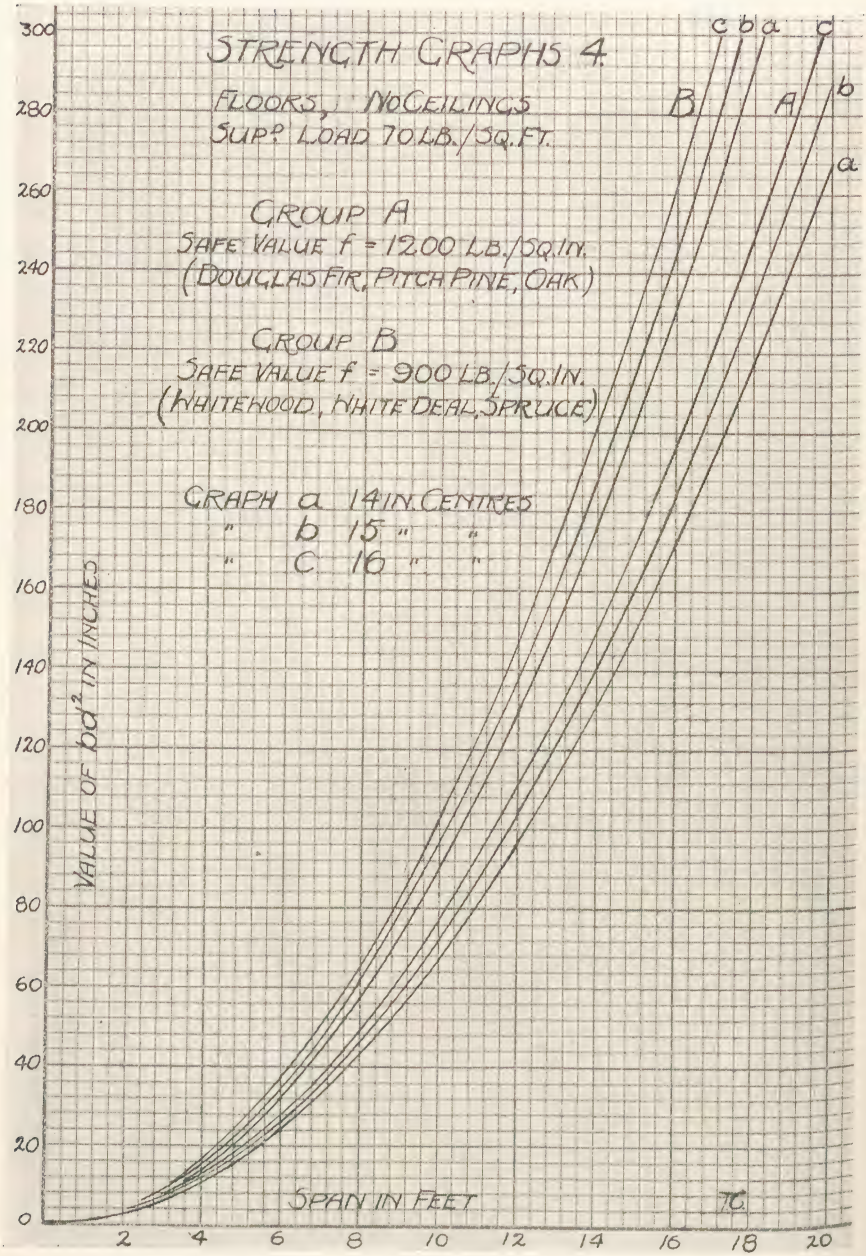


Plate IV.—GRAPHS SHOWING THE SECTIONAL AREAS OF JOISTS FOR BALTIC FIR, SPRUCE, ETC., AND DOUGLAS FIR, PITCH PINE, OAK, ETC., FOR FLOORS WITHOUT CEILINGS, OR WITH LIGHT CEILINGS OF CEILING-BOARDS

Trimmer and Trimming Joists

In addition to the superimposed loads and their own weight, these joists have to carry the ends of other joists. This gives a more complicated bending moment, and it is necessary to understand the theory a little before we can equate against the resistance of the beam. There are numerous methods of finding the increase of thickness necessary for these joists, as the depth is usually the same as the common joists, but they are not always satisfactory. Hence, the reader should study the explanation following the plates of graphs so that he can design them for himself.

The following are taken from local by-laws: "A trimming joist carrying a trimmer joist up to 3 ft. from one end shall be increased $1\frac{1}{2}$ in. in thickness over that of the common joist having the same span." "A trimmer joist, carrying not more than six common, or tail, joists, shall be increased $\frac{1}{4}$ in. in thickness, for each joist carried, over that of the common joist having the same span." "Other cases must be designed."

There are so many special cases excluded from the above conditions that it is often necessary to design them. In the case of trimmer joists, however, practical considerations usually dictate a larger size than strength requirements. Another consideration arises in the trimmer joist. The cutting and morticing for the ends of the tail joists weakens the timber considerably, owing to the weakness in shear resistance. Where hangers are used to carry the ends of the tail joists the design is simplified considerably, and a smaller section of joist may be used.

GRAPHS

The graphs on Plates I to VIII have been plotted to enable those not wishing to calculate the sizes for themselves to select suitable sizes for any timbers or spans. The calculations have been based on a superimposed load of 70 lb. per foot super, plus 20 per cent. for ceiled floors and 10 per cent. for unceiled floors.

Although the common timbers are mentioned on the graphs it will be understood that the graphs are applicable to any timbers having the same approximate values of f and E, and these values can be obtained for unusual timbers from books on materials. The graphs are of special value in border-line cases, and a judicious selection will often mean a saving in cost; also, the results obtained from the graphs will satisfy the most exacting by-laws.

Strength Graphs

These graphs are for timbers having safe values of f of 900 lb., 1,000 lb., and 1,200 lb. per square inch respectively, such as whitewood (white deal), redwood (red or yellow deal), and Douglas fir. In every case three graphs are given, for 14-in., 15-in., and 16-in. centres respectively. Plates I and II are for floors with ceilings, and Plates III and IV are for floors without ceilings, or with light ceilings such as fibre ceiling-boards.

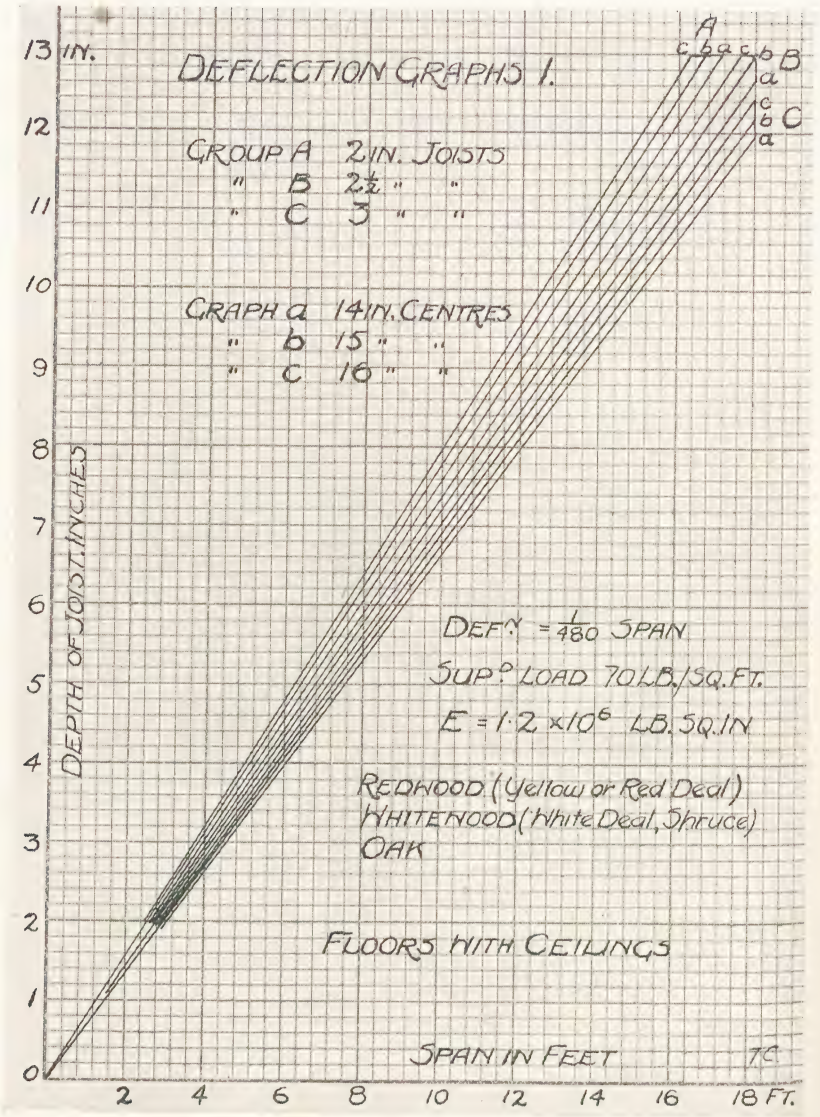


Plate V.—GRAPHS SHOWING THE SIZES OF JOISTS REQUIRED FOR SPECIALLY RIGID FLOORS WITH PLASTER CEILINGS—FOR REDWOOD, SCOTS PINE, BALTIC FIR, SPRUCE, OAK, ETC.

Using the Strength Graphs. Plate I

If we require to know the size of a redwood joist of, say, 13-ft. effective span at 15-in. centres, we refer to the bottom of the graph, which shows the span in feet. Vertically above the span, on the middle graph *b*,

read the height of the intersection, which is 160. This is the value of bd^2. Hence, if we use 2-in. joists, $d^2 = \frac{160}{2} = 80$, $\therefore d = \sqrt{80} = 9$ in. Therefore the required joist is 13 ft. 4 in. by 9 in. by 2 in., where the distance between the walls is 12 ft. 8 in. This allows for a 4-in. bearing on each wall.

Plate II

If the timber is Douglas fir, refer to the graphs on Plate II. An example is shown for 12-ft. 6-in. effective span, at 14-in. centres, which gives $bd^2 = 116$, $\therefore d^2 = \frac{116}{2} = 58$, $\therefore d = 7{\cdot}6$ in. for a 2-in. joist. If the joist is of Baltic fir, at 15-in. centres, then $bd^2 = 162$, $\therefore d^2 = 81$, $\therefore d = 9$ in.

Plate III

These graphs are for floors with redwood joists without ceilings, or with light ceiling-boards instead of plaster. The example shows the value for a joist of 14-ft. effective span, at 15-in. centres. In this case $bd^2 = 172$, therefore, for a 3-in. joist, $d^2 = \frac{172}{3} = 57\frac{1}{3}$, $\therefore$ size of joist required = 7·6 in. by 3 in., or 9·3 in. by 2 in., which means 8-in. by 3-in., or 10-in. by 2-in., joists. Owing to the high factor of safety and the allowed load, 9 in. by 2 in. could be used for ordinary work.

In every case the readings will give a joist sufficiently strong for the purpose, and in most cases it will be sufficiently rigid for ordinary purposes if the usual proportions of depth and thickness are adopted, but it is advisable to check on the deflection graphs, especially if a plaster ceiling is carried.

Deflection Graphs

It is intended that these graphs should be used in conjunction with the strength graphs. Plates V and VI, however, are intended for high-class work, where every precaution has been taken to provide a rigid floor, and for upper floors of offices. As stated previously, the strutting and flooring tend to spread the deflection, and the total equivalent dead load of 84 lb. per foot super is rather high for ordinary domestic floors. Also, the maximum deflection of $\frac{1}{180}$ span is not always demanded. The reader should bear this in mind when making his selection.

Plates VII and VIII are satisfactory for ordinary domestic floors with plaster ceilings, or for high-class floors with ceiling-boards. It is suggested that these graphs, Plates VII and VIII, be used for purposes of checking the strength graphs, as they satisfy the requirements of most by-laws. They are calculated for a total equivalent dead load of 77 lb. per foot super of floor area.

The graphs are in groups of three, for 2-in., $2\frac{1}{2}$-in., and 3-in. joists, and for 14-in., 15-in., and 16-in. centres respectively.

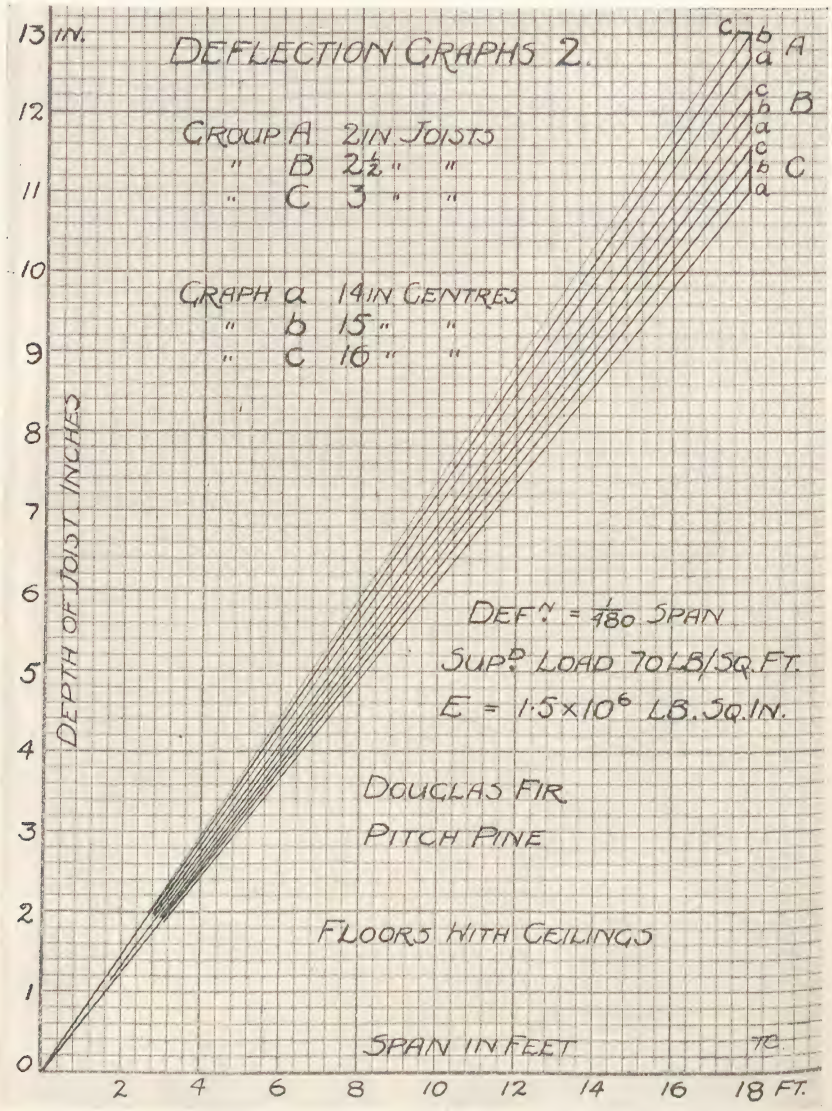


Plate VI.—GRAPHS SHOWING THE SIZES OF JOISTS REQUIRED FOR SPECIALLY RIGID FLOORS WITH PLASTER CEILINGS FOR DOUGLAS FIR, PITCH PINE, ETC.

Plates V and VII are for any timbers having an approximate value of 1,200,000 lb./sq. in. for E, such as redwood, whitewood, spruce, oak, etc. Plates VI and VIII are for a value of E of 1,500,000 lb./sq. in., for such timbers as pitch pine, Douglas fir, etc.

Using the Deflection Graphs

If a yellow or white deal joist is required for an ordinary house floor with ceiling, refer to Plate VII. Assuming a joist of 12-ft. effective span, 2 in. thick, and at 15-in. centres, then the depth is $8\frac{1}{2}$ in.

Turn to Plate I, which gives a value of 138 for bd^2, $\therefore d^2 = 69$, $\therefore d = 8{\cdot}3$ in. Next turn to Plate II, which gives a value of 150 for bd^2, $\therefore d^2 = 75$, $\therefore d = 8{\cdot}7$ in. Therefore every test suggests a 9-in. by 2-in. joist, whether redwood or whitewood.

Select a joist suitable for any floor, above the entrance floor, of a suite of offices, assuming 15-ft. effective span, and Douglas-fir joists, and a plaster ceiling. Refer to Plate II, Group A, and if the joists are at 14-in. centres, then $bd^2 = 166$. Now turn to Plate VI, and for 2-in. joists the depth is 10·6 in.; for $2\frac{1}{2}$-in. joists 9·8 in.; and for 3-in. joists 9·2 in. So that, for any thickness, a bigger section is required against deflection than for strength. In this case a 9-in. by 3-in. joist would probably be selected, and would be quite satisfactory.

EXPLANATION OF FORMULÆ

Moments

It is necessary to understand the meaning of a *moment* before we can understand bending moments. The moment of a force is the *turning effect* of a force about an axis. It is the product of "force × distance," where distance is measured perpendicularly from the axis to the force. A moment is expressed in compound units, that is, the force may be in pounds, hundredweights, or tons, and the distance may be in feet or inches, therefore when they are multiplied together the answer is in lb. ft. or lb. in., as the case may be. For instance, if a force of 10 lb. turns about an axis 10 ft. away, then the *leverage*, or *turning effect*, or *moment*, of the force is 10 lb. × 10 ft. = 100 lb. ft., or 10 lb. × 120 in. = 1,200 lb. in. When we are designing wood joists we use units of pounds and inches.

Bending Moments

The bending moment at any cross-section of a joist or beam is the effect of the external forces tending to bend the beam at that particular cross-section. It is "the algebraic sum of the moments of the external forces acting on one side of the section."

Fig. 3 shows a beam with a central concentrated load of 10 tons, that is, the load of 10 tons is resting on a comparatively short length of the beam. Each wall will support half of the load, i.e. 5 tons. We call these the *reactions* of the supports, and distinguish them by calling them R_A and R_B.

To find the bending moment at the section S, say 3 ft. from R_B, we take the moments of the forces acting *either* to the left *or* to the right of the section S. On the right-hand side there is only one force, R_B, therefore $BM_S = 5$ tons × 3 ft. = 15 tons ft. On the left-hand side there

are two forces acting, 10 tons and 5 tons, but the force of 10 tons turns one way, *anti-clockwise*, and the force of 5 tons turns the other way, *clockwise*. Therefore we have to find the difference between the effects of these two forces, or the *algebraic sum*. Therefore $BM_S = 5$ tons $\times$ 7 ft. $-$ 10 tons $\times$ 2 ft. $= 35 - 20 = 15$ tons ft., as before.

BM Diagram—Concentrated Load

If we select any convenient scale we can draw a diagram to show the bending moment for any section along the beam. Draw a level line, and at convenient distances set off the BM perpendicular to the line, as shown in Fig. 3. The following Table gives the BM at intervals of 1 ft. from R_A and R_B.

From R_A	*BM*	*From RB*	*BM*
ft.	*tons ft.*	*ft.*	*tons ft.*
0	0	0	0
1	5	1	5
2	10	2	10
3	15	3	15
4	20	4	20
5	25	5	25

Plot these values to a scale of, say, 1 in. = 10 tons ft., and the result is a triangle as shown in Fig. 3. When the loads are concentrated the diagram always consists of straight lines. If we calculate the BM in terms of W and L for the position of maximum bending moment, which is at the middle of the span in this case, we have $R_A \times \frac{1}{2}L$, but $R_A = \frac{1}{2}W$, $\therefore$ $BM = \frac{1}{2}W \times \frac{1}{2}L = \frac{1}{4}WL$.

BM Diagram—Distributed Load

Fig. 4 shows the same load uniformly distributed along the beam, that is, 1 ton per foot of span. Again the reactions of the supports are both 5 tons. In this case it is necessary to find the *algebraic sum* at every section considered. At the section S, 2 ft. from R_B, the BM is 5 tons $\times$ 2 ft. *less* the moment of the 2 ft. of load on the beam. This load of 2 tons may be considered as concentrated at its centre of gravity, i.e. at a distance of 1 ft. from S. Therefore the moment is 2 tons $\times$ 1 ft. and the $BM_S = 5 \times 2 - 2 \times 1 = 8$ tons ft. Calculating a number of values for different positions along the beam, and plotting them to scale, as for Fig. 3, the outline shown in Fig. 4 is obtained. This outline is a parabola and is always given by the BM diagram for a distributed load. The Table on page 434 gives the BM at intervals of 1 ft. from R_A and R_B.

The calculations in terms of W and L, for the position of maximum BM, are $\frac{1}{2}W \times \frac{1}{2}L - \frac{1}{2}W \times \frac{1}{4}L = \frac{1}{4}WL - \frac{1}{8}WL = \frac{1}{8}WL$, which is the bending moment for a common joist.

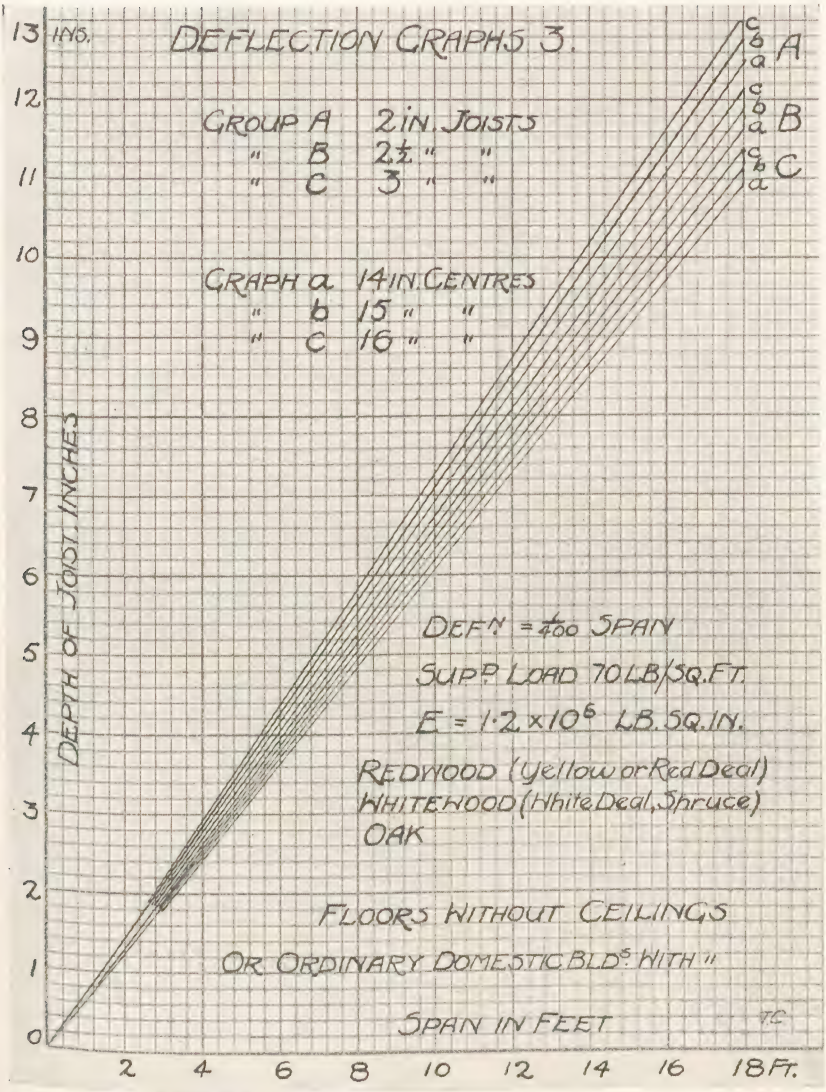


Plate VII.—GRAPHS SHOWING THE SIZES OF JOISTS REQUIRED FOR RIGID FLOORS WITH VERY LIGHT CEILINGS OR FOR ORDINARY HOUSES WITH PLASTER CEILINGS —FOR YELLOW DEAL, SCOTS PINE, BALTIC FIR, ETC.

Concentrated Loads—Reactions

When the loads are not symmetrical on the beam the reactions at the supports are unequal, and it is necessary to calculate for the reactions before finding the bending moments. Fig. 5 shows a beam of 16-ft. span

carrying three concentrated loads. The beam must be in a condition of equilibrium under the action of loads and reactions, if no movement takes

From R_A	*BM*	*From* R_B	*BM*
ft.	*tons ft.*	*ft.*	*tons ft.*
0	0	0	0
1	$4\frac{1}{2}$	1	$4\frac{1}{2}$
2	8	2	8
3	$10\frac{1}{2}$	3	$10\frac{1}{2}$
4	12	4	12
5	$12\frac{1}{2}$	5	$12\frac{1}{2}$

place. Therefore we take the moments of all the forces acting on the beam, and assume one of the reactions as the axis. Taking moments about R_A we have :—

$R_B \times 16$ (anti-clockwise) and $6 \times 4 + 8 \times 10 + 4 \times 14$ (clockwise), but clockwise moments = anti-clockwise moments, for equilibrium.

Therefore $R_B \times 16 = 24 + 80 + 56$ tons ft., $\therefore R_B = \frac{160}{16} = 10$ tons.

If R_B supports 10 tons, then R_A must support the total load — 10 tons, $\therefore R_A = 18$ tons — 10 tons = 8 tons. The same results will be obtained if moments are taken about R_B.

BM Diagram

The bending moment may now be obtained for any required position, but it is only necessary to calculate for the positions under the loads, as the diagram consists of straight lines. Under the 4-tons load the BM = $R_B \times 2$ ft. $= 10 \times 2 = 20$ tons ft. ; and under the 6-tons load it is $R_A \times 4$ ft. $= 8 \times 4 = 32$ tons ft. Under the 8-tons load it is $R_B \times 6$ ft. — 4 tons $\times$ 4 ft. $= 10 \times 6 - 4 \times 4 = 60 - 16 = 44$ tons ft., which the diagram shows is the maximum bending moment.

Trimmer Joists

The last example is very similar to a trimmer joist except that in the latter the loads and the spacing of the loads are more uniform. In Fig. 6 is shown a trimmer carrying three trimmed, or tail, joists, each of which transfers 6 ft. $\times$ $1\frac{1}{4}$ ft. $\times$ w lb. If the superimposed load is 70 lb. per foot super, then $w = 70 +$ 20 per cent. of 70 lb. = 84 lb. per foot super. Therefore the load on each trimmed joist carried by the trimmer = 630 lb., as shown in Fig. 7. The reactions are 945 lb., carried by the trimming joist, $\therefore$ the BM, at the middle of the trimmer, is 945 $\times$ 30 in. — 630 $\times$ 15 in. = 18,900 lb. in.

Trimming Joist

In this case the joist carries a load like a common joist plus the load of 945 lb. from the trimmer ; that is, there is both a distributed load and

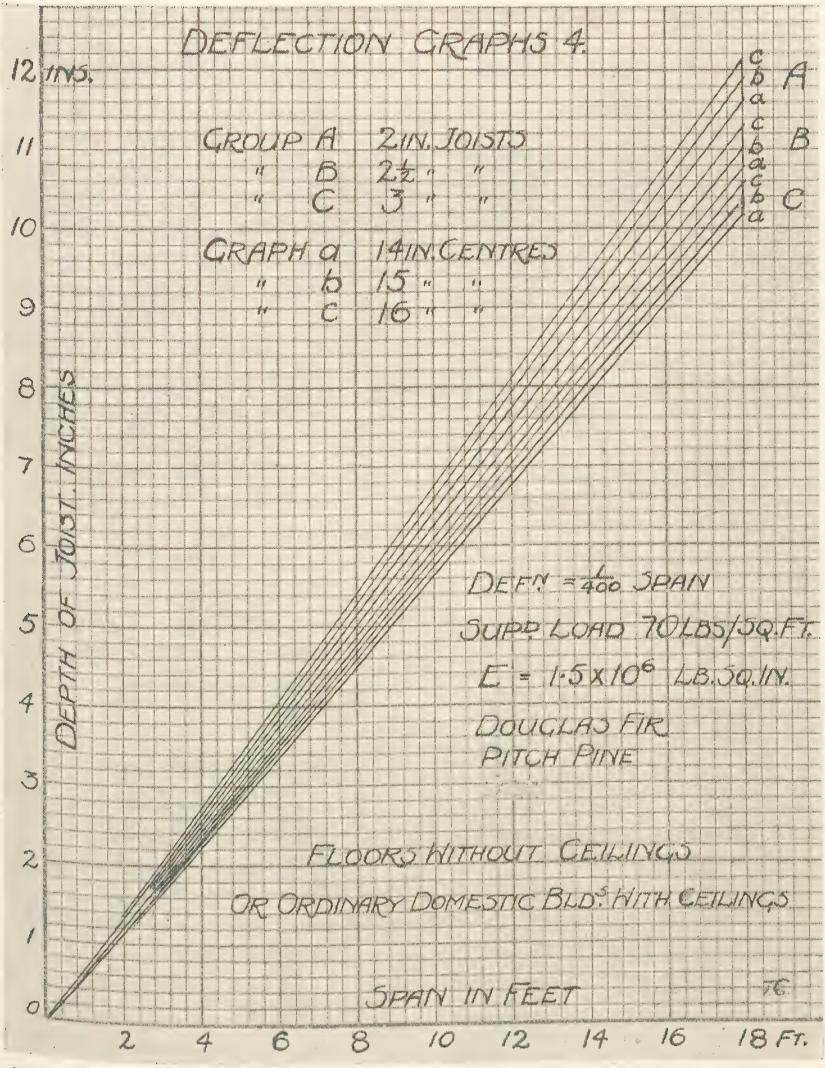


Plate VIII.—GRAPHS SHOWING THE SIZES OF JOISTS REQUIRED FOR RIGID FLOORS WITH VERY LIGHT CEILINGS OR FOR ORDINARY DOMESTIC BUILDINGS WITH PLASTER CEILINGS, FOR DOUGLAS FIR, PITCH PINE, ETC.

a concentrated load on the same joist. The BM for the distributed load is $\frac{WL}{8}$, $= \frac{16 \text{ ft.} \times 1\frac{1}{4} \text{ ft.} \times 84 \text{ lb.} \times 192 \text{ in.}}{8} = 40{,}320$ lb. in. Also, W = 1,680 lb., ∴ the reactions are 840 lb. This bending moment can now be drawn as a parabola, as shown in Fig. 8, above the horizontal line, to a scale of, say, ½ in. = 10,000 lb. in.

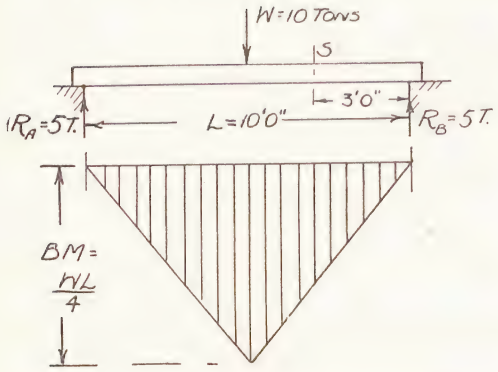


Fig. 3.—BENDING-MOMENT DIAGRAM FOR CENTRAL CONCENTRATED LOAD

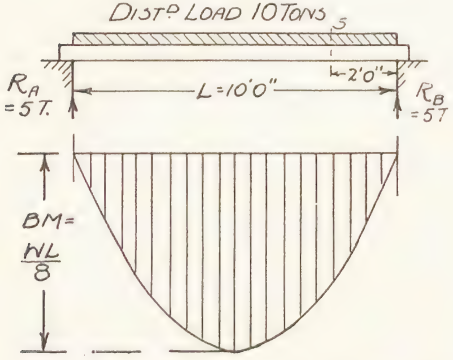


Fig. 4.—BENDING-MOMENT DIAGRAM FOR DISTRIBUTED LOAD

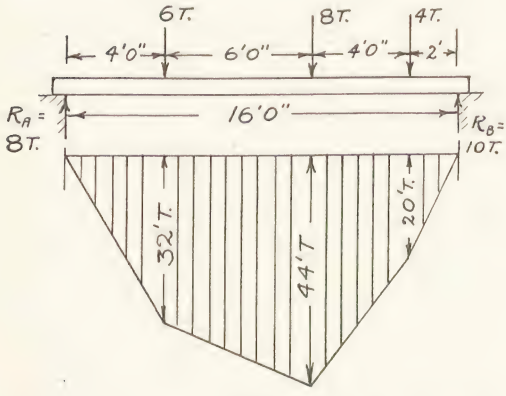


Fig. 5.—BENDING-MOMENT DIAGRAM FOR SEVERAL CONCENTRATED LOADS

Drawing a Parabola

Set out the bending moment of 40,320 lb. in. at the middle of the horizontal line. This gives the height of the parabola. Complete the rectangle by drawing *ab* and *bc*. Divide these lines into the same number of equal parts, say four, as in Fig. 8. From the divisions on the vertical line *ab* draw radiating lines to *c*, as 3-*c*, 2-*c*, 1-*c*. From the divisions on the horizontal line *bc* drop perpendiculars to meet the radiating line having the same number. Draw a free curve through the points of intersection for one-half of the parabola. The other half may be completed in the same way, or by symmetrical lines.

Concentrated Load

The reactions due to the concentrated load of 945 lb. are $R_B \times 16 = 945 \times 4$, $\therefore R_B = 236\frac{1}{4}$ lb., $\therefore R_A = 708\frac{3}{4}$ lb., say 709 and 236 lb. respectively.

Then BM $= 709 \times 4 =$ 2,836 lb. ft., or 34,030 lb. in. Set off this value below the horizontal line, as in Fig. 8, under the load, and to the same scale as the parabola, $\frac{1}{2}$ in. = 10,000 lb. in.

The greatest distance across the combined diagram is the *maximum* bending moment, and is about 66,000 lb. in. measured to the BM scale.

Shear Force (S)

The shear force acting on any section of a beam is the effect of the external forces tending to make one surface slide over the other. The magnitude of the shear force, at the section, is the algebraic *sum of the forces* acting on one side of the section. This is called the vertical SF, and at any section it is equal to the difference between the reaction and the forces between the support and the section.

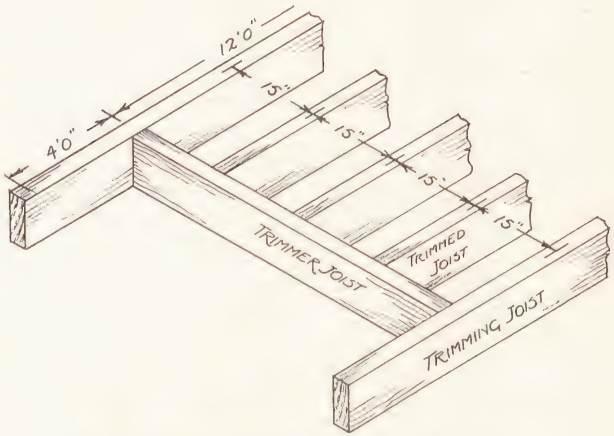


Fig. 6.—ARRANGEMENT OF JOISTS TO HEARTH

The shear force can be shown by a diagram, drawn to a suitable scale, in the same way as the bending moment.

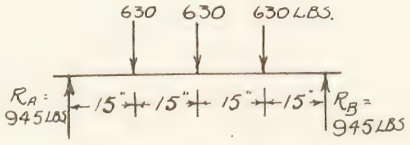


Fig. 7.—LOAD ON TRIMMER JOIST

Shear-force Diagrams

Fig. 9A shows the shear-force diagram for a central load of 10 tons. Draw a horizontal line equal to the span, and at the ends set off the reactions, as shown, to any convenient scale. Consider a section of the beam 2 ft. from R_A. The shear force is equal to the forces acting on the left of the section, but there is only one force, R_A, $\therefore$ SF $= R_A =$

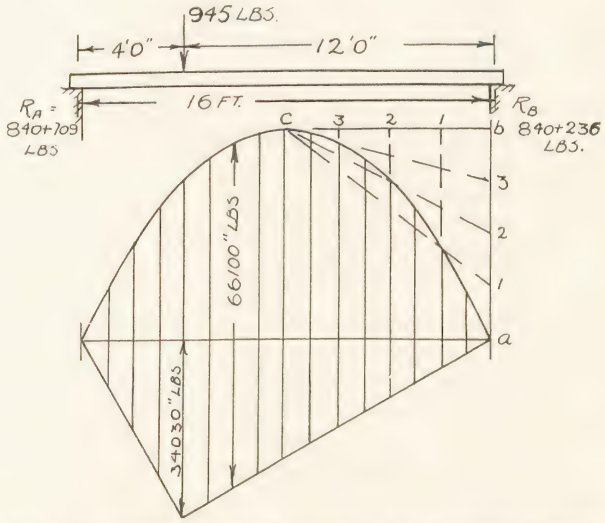


Fig. 8.—BENDING-MOMENT DIAGRAM FOR TRIMMING JOIST

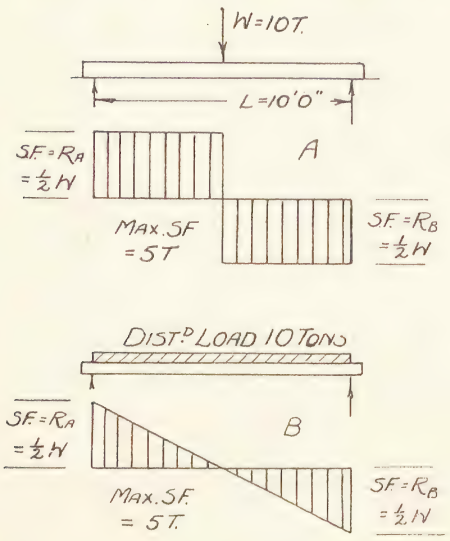


Fig. 9.—SHEAR-FORCE DIAGRAMS FOR CENTRAL AND DISTRIBUTED LOADS

5 tons. Repeat for other sections along the beam, and the same result is obtained up to the load of 10 tons. Immediately to the right of W there are two forces acting, R_A and W, but R_A is acting upwards and W downwards. The algebraic sum is again 5 tons. If the same procedure is adopted from R_B it is found that the shear force is 5 tons all along the beam. This is represented by the diagram in Fig. 9A, which shows the maximum SF to be $\frac{1}{2}$W.

Fig. 9B shows the shear-force diagram for a distributed load of 1 ton per foot run. Considering a section 1 ft. from R_A, the forces to the left of the section are R_A, and 1 ton of load on the beam. The algebraic sum of these two forces $= R_A - 1$ ton, $\therefore$ SF, 1 ft. from R_A, $= 4$ tons. Similarly, 2 ft. from R_A, it is $R_A - 2$ tons, etc. If the calculations are taken at small intervals, the diagram shown in Fig. 9B is obtained, which again shows the maximum shear force to be $\frac{1}{2}$W. The reader should note that the position of least shear is the position of maximum BM, and the position of maximum shear is the position of least BM.

Now consider the shear-force diagram for the trimming joist shown in Fig. 8. Draw a horizontal line and set off the reactions as before. The distributed load is 105 lb. per foot run of joist. Therefore 1 ft. from R_A drop down 105 lb., 2 ft. from R_A drop down 2×105 lb., and so on, until at 4 ft. from R_A it is necessary to drop down $4 \times 105 + 945$ lb. for the concentrated load. Proceeding along the beam in this way, the shear-force diagram is obtained as shown in Fig. 10. The same result would be obtained if the calculations were taken at distances from R_B, which shows $S_{max} = R_A = 1{,}549$ lb.

Longitudinal Shear

The vertical shear stresses in the joist due to the action of the external forces, represented by the shear force, give rise to horizontal shear stresses of equal intensity. The shear, however, is not equally distributed over the section of the joist, but increases from zero at the outer edges to a maximum at the neutral axis, where it is $1\frac{1}{2} \times$ the *mean shear* across the section; and the mean shear $= S \div bd$. This variation of shear stress

in the depth of the beam can be represented by a parabola with maximum ordinate at the neutral axis of $\frac{3}{2}\frac{S}{bd}$.

It is important to test for shear when the joist is very deep compared with its length, and in the making of joints. Timber is very weak in longitudinal shear, that is, along the grain, especially when the member is subjected to bending as in a joist. The safe values of *bending shear* are given in the Table on page 424.

RESISTANCE OF BEAMS

If a beam is loaded to destruction, as shown in Fig. 11, the top part will fail by crushing, due to compression, and the lower part will extend, or tear asunder, due to tension. The effect in both cases will be greatest at the outer edges of the beam, and will gradually diminish towards the middle of the depth of the beam, where the two different kinds of stress change from one to the other. Obviously where the change takes place there can be no stress, and this layer, where the change takes place, is called the neutral layer, or neutral axis.

Resistance Areas

The effect of this variation of stress in the depth of the beam is illustrated by a diagram in Fig. 12, if we imagine that all the fibres are acting with the maximum resistance. Because the resistance of the wood is equal in tension and compression, the neutral axis, NA, is at the middle of the depth, therefore the effect of the resistance is shown by two equal shaded triangles, one resisting tension and the other compression. These shaded portions of the section of the beam, shown at B, Fig. 12, are called the *inertia*, or *resistance, areas*, and they do the whole work of resistance, theoretically. If all of the fibres within these triangles are doing equal work we can consider them all acting together, as a combined force, at the centre of gravity of each triangle, as shown at C and T, Fig. 12A.

Fig. 13 is another way of illustrating the same thing, but this time it is a pictorial view, and the variation of stress is illustrated as wedges. The top wedge represents the forces resisting compression and acting at the central force C, and the bottom wedge the forces resisting tension acting at T.

Moment of Resistance

The two forces C and T form a couple, and the distance between them is called the arm of the couple, or *lever arm*, LA. The magnitude of a couple is obtained by finding the product of *one force* $\times$ lever arm. Therefore the moment of resistance is $C \times LA \times f$, where f is the maximum stress acting in the fibres.

The forces C and T are the resultants of all the little forces represented by the shaded triangles in Fig. 12B. Therefore the magnitude of C is

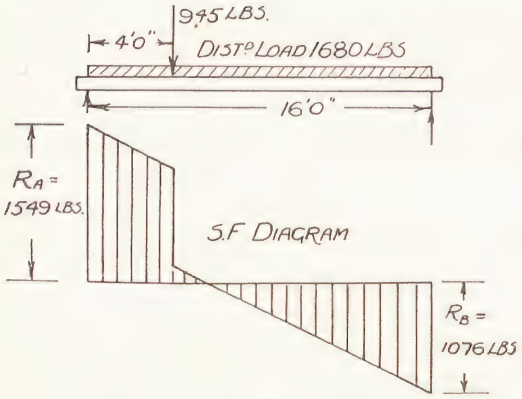


Fig. 10.—SHEAR-FORCE DIAGRAM FOR TRIMMING JOIST

the area of the triangle *efg*, which is $\frac{1}{4}bd$, where b is the thickness of the beam and d is the depth. The lever arm $= \frac{2}{3}d$.

Therefore the moment of resistance $= \frac{1}{4}bd \times \frac{2}{3}d \times f = \frac{bd^2}{6} \times f$. The value $\frac{bd^2}{6}$ is called the modulus of section, Z, and is simply a function of the size and shape of the section. It has nothing to do with the kind of material.

In the design of beams, the moment of resistance $\frac{fbd^2}{6}$ equals the maximum bending moment :—

$$\text{BM} = \text{MR} \quad \text{or} \quad \text{BM} = fZ$$

Design of Trimming Joists

We can now apply the above formula to the trimming joist in Fig. 6. The BM was found in Fig. 8 to be 66,000 lb. in., $\therefore 66{,}000 = \frac{fbd^2}{6}$. Assuming f to be 1,000 lb. per square inch, then $bd^2 = \frac{66000 \times 6}{1000} = 396$. The depth is dictated by the depth of the common joist, which is 11 in., $\therefore b = \frac{396}{11 \times 11} = 3{\cdot}27$ in., say $3\frac{1}{2}$ in., which satisfies the demands of the by-law previously stated, although the trimmer is more than 3 ft. from the end.

DEFLECTION

The derivation of the deflection formula is too mathematical to explain in a short practical article, but it is possible to explain how the symbols used in the formula are derived.

Stress, Strain, and Modulus of Elasticity

Elasticity is the property of a material to recover itself after being distorted, or strained, by a load or force. This power of recovery, however, is limited, and if a material is stressed, by the external forces, above a certain amount, called the elastic limit, the material will not resume its original condition but will retain a *permanent set*.

One of the laws of elasticity, Hooke's law, states that "the strain varies as the stress within the elastic limit." Therefore if stress $\propto$ strain, then stress = strain $\times$ a *constant*. This constant is called the modulus of elasticity, or Young's modulus, and is denoted by E.

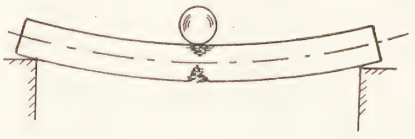


Fig. 11.—EFFECT OF LOADING A BEAM TO DESTRUCTION

Stress is measured by finding the amount of force acting on each unit of sectional area, and $= \dfrac{\text{force}}{\text{sectional area}}$.

Strain is measured by finding the alteration of length per unit of length, due to the action of the force, and $= \dfrac{\text{alteration of length}}{\text{original length}}$.

Example.—If a hanger 5 ft. by 3 in. by 2 in. stretches 0·1 in. under a force of 12,000 lb., find the value of E.

$$\text{E} = \text{stress} \div \text{strain} = \frac{12000}{3 \times 2} \div \frac{\cdot 1}{60} = \frac{12000}{6} \times \frac{60}{\cdot 1} = 1{,}200{,}000 \text{ lb./sq. in.}$$

The value of E for the various structural materials has been obtained by experiment, and may be obtained from any text-book dealing with the strength of materials.

Moment of Inertia (I)

If we imagine the section of a beam as consisting of a large number of very small areas, and multiply each little elementary area by the *square of its distance* from an axis, then the sum of all these calculations will be the moment of inertia about that axis. For instance, let each little area be a, and its distance from the axis d, then :—

$$\text{I} = a_1 d_1^2 + a_2 d_2^2 + a_3 d_3^2, \text{ etc.} = \textit{the sum of } ad^2 = \Sigma\, ad^2.$$

This calculation entails rather advanced mathematics, but the following will help the reader to understand how the value of I is obtained for a rectangular section, in which the axis is the neutral axis of the section. Fig. 14 shows the section of a 10-in. by 6-in. beam. If we imagine the section divided into a large number of small strips, we can calculate the approximate moment of inertia for the section. In the

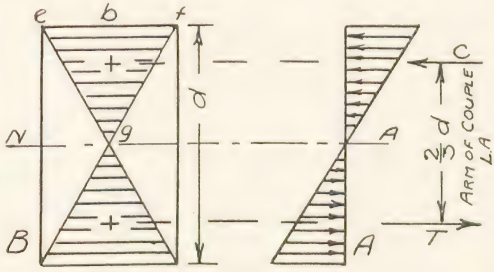


Fig. 12.—DIAGRAM SHOWING DISTRIBUTION OF STRESS IN SECTION OF JOIST

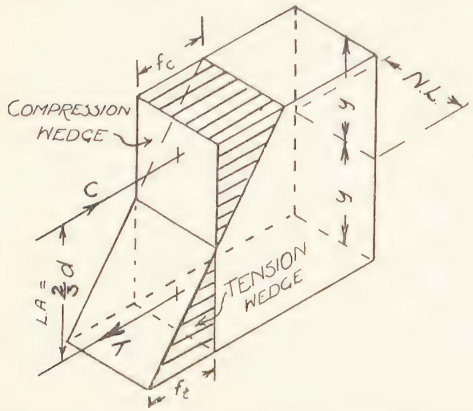


Fig. 13.—DIAGRAM SHOWING DISTRIBUTION OF STRESS IN JOIST

example we have taken very large strips, but they will serve to illustrate the principle.

The area of each strip is 6 in. × 1 in. = 6 sq. in., ∴ the moment of inertia of the strip near the neutral axis is 6 sq. in. × ·5², because ·5 is the distance from the centre of gravity of the strip to the neutral axis. If we deal with each strip, above the neutral axis, in the same way, and multiply by 2 for the lower half, and add all the results together, we shall have the approximate value of I.

$$I = 2(6 \times \cdot5^2 + 6 \times 1\cdot5^2 + 6 \times 2\cdot5^2 + 6 \times 3\cdot5^2 + 6 \times 4\cdot5^2)$$
$$\therefore\ I = 6 \times 2(\cdot5^2 + 1\cdot5^2 + 2\cdot5^2 + 3\cdot5^2 + 4\cdot5^2)$$
$$\therefore\ I = 12 \times 41\cdot25 = 495 \text{ in.}^4$$

This result is not quite correct, but the smaller we take the strips, the more accurate the result.

Fig. 14 also illustrates a simple mathematical treatment. Let A and A_1 be the areas of the shaded triangles; x and x_1 the distances of their centres of gravity from the neutral axis; y and y_1 the distances of the extreme or outer fibres from the neutral axis: then $I = Ayx + A_1y_1x_1 = 2Ayx$, because the two halves of the section are symmetrical. But $A = \frac{bd}{4}$, $x = \frac{d}{3}$, and $y = \frac{d}{2}$, $\therefore I = 2 \times \frac{bd}{4} \times \frac{d}{3} \times \frac{d}{2} = \frac{bd^3}{12}$.

Substituting the values of b and d, then :—

$\frac{bd^3}{12} = \frac{6 \times 10 \times 10 \times 10}{12} = 500$ in.⁴, which is the correct value of I.

The moment of inertia, I, divided by y, gives the modulus of section, Z, because $\frac{I}{y} = \frac{bd^3}{12} \div \frac{d}{2} = \frac{bd^2}{6} = Z$.

Calculations

The reader will have observed that there is a certain amount of approximation in the design. This applies especially to the values adopted for f, E, and the superimposed loads. It is necessary to select these values judiciously, but there is no advantage in striving for a high degree of accuracy in the calculations. It is better to select *approximate*

values, to simplify the calculations and so reduce the chances of error, but it is important to err on the side of safety when dealing with the strength of a joist.

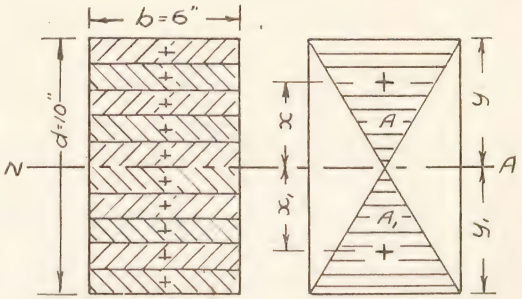


Fig. 14.—MOMENT-OF-INERTIA DIAGRAM

Laying the Joists

The previous considerations assume timber of average quality. In nearly every consignment, however, there are inferior pieces, and it is the responsibility of the carpenter to select and lay the joists to the best advantage. Large knots should be on the top edge. Bowed joists should have the rounded edge uppermost. If these two conditions clash the joist should be cut and used for some other purpose. Waney edge at the ends should be on top to ensure sufficient bearing ; but if it is not at the ends it should be underneath, to allow for jointing the floorboards. Joists with cross-grain should be scrapped or utilised in short lengths, and all timber showing wormholes or signs of decay should be condemned.

Morticing and housing should be near the neutral axis. On no account should the bottom edge be cut or notched, unless it has been allowed for in the design ; and even then it has a weakening effect in excess of the reduction of depth. Joists are stronger if the annual rings run in the direction of the depth, rather than across the thickness, and these should be selected for the long joists in the middle of the floor. The ends of joists for adjacent rooms, or houses, should not be in contact, as they readily conduct sound.

TABLE OF BM, S, AND E

Type of Beam and Loading	*Bending Moment*	*Shear Force*	*Modulus of Elasticity, E*
Cantilever with load at end . . .	WL	W	$\frac{1}{3}\frac{WL^3}{EI}$
Cantilever with load uniformly distributed	$\frac{WL}{2}$	W	$\frac{1}{8}\frac{WL^3}{EI}$
Beam resting on end supports. Central load	$\frac{WL}{4}$	$\frac{W}{2}$	$\frac{1}{48}\frac{WL^3}{EI}$
Beam resting on end supports. Distributed load	$\frac{WL}{8}$	$\frac{W}{2}$	$\frac{5}{384}\frac{WL^3}{EI}$

ROOF CONSTRUCTION

PART III.—KING-POST ROOF TRUSS

FOR spans of more than 20 ft. a truss becomes necessary, and what is known as a *king-post truss* is employed. It consists of a tie-beam, two principal rafters, two struts, and a king-post. As a rough guide we may take it that the tie-beam requires a support every 15 ft., and the principal rafter a support every 8 ft. According to this rule this type of truss is suitable for spans up to 30 ft. (see Fig. 1).

Principle of King-post Truss

The king-post supports the tie-beam at the centre, and although a vertical member it is subjected to tensional stress alone. The principal rafters are in compression, and are supported in the middle by the struts from the base of the king-post. These also are in compression. The tie-beam is in tension, but where it carries a ceiling load it will also be subjected to transverse bending.

The stress in the principal rafters tends to bend, and consequently, as with the tie-beam, their depth must be greater than their width or thickness. The struts, having no definite transverse strain, should be made as nearly as possible square in section. The purlins are supported by the truss, and in turn support the roofing, i.e. common rafters, boarding, battens, slates, or tiles.

The dimensions given in the Table below are minimum sizes, and may be increased if desired. This has been done on the diagrams, Fig. 1.

DIMENSIONS OF TIMBERS FOR KING-POST ROOF TRUSSES
10 FT. APART, PITCH 30°, SLATED

Span	*Thickness of All Truss Members*	*Minimum Breadth on Elevation*			
		Tie-beam	*Principal Rafter*	*King-post*	*Struts*
ft.	*in.*	*in.*	*in.*	*in.*	*in.*
20	4	8	4	3	2
22	4½	9	4	3½	2¼
24	5	10	4¼	3½	2½
26	5½	10	4¼	4	2¾
28	6	11	4½	4	3
30	6½	12	4½	4½	3¼

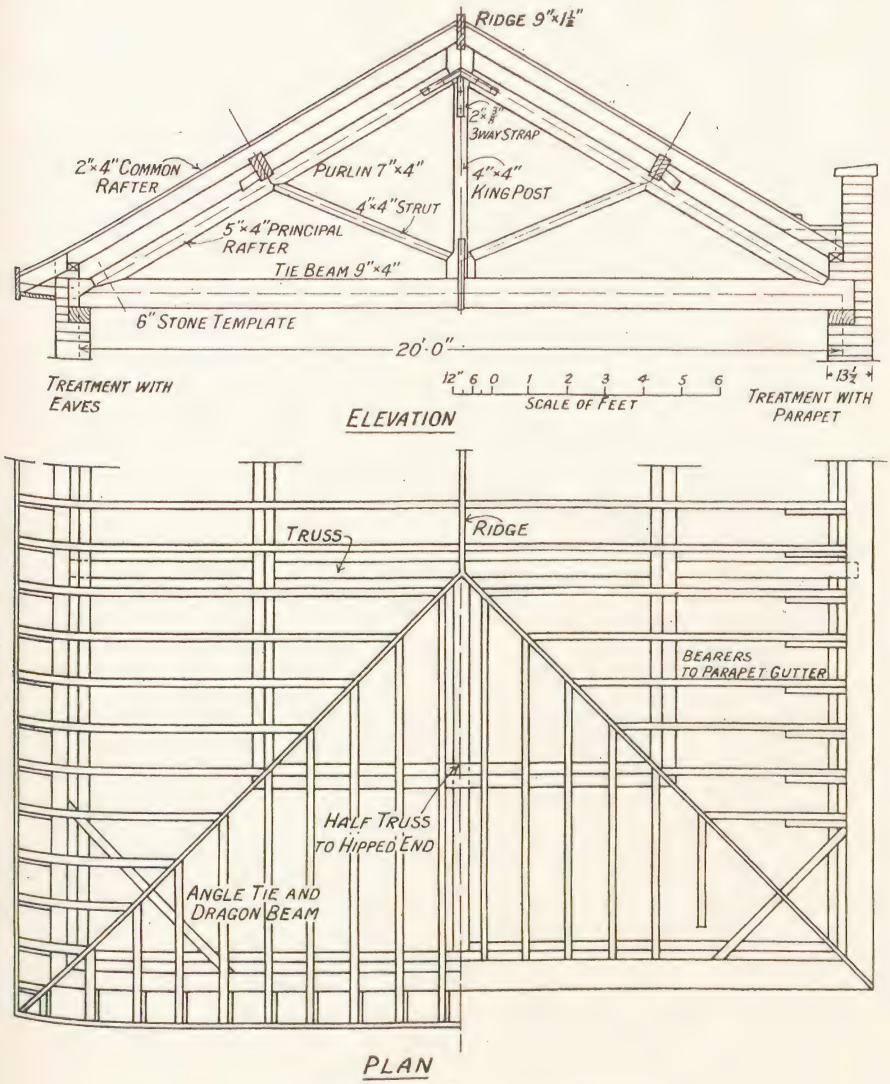


Fig. 1.—KING-POST ROOF TRUSS WITH HIPPED END

All the members of a king-post roof truss are made the same thickness, with the exception sometimes of the struts. This allows the iron straps to be bolted to the surface to hold the joints together.

The Purlins

The purlins are generally placed over the top of the struts, and as there are only two struts in a king-post truss the purlins are consequently

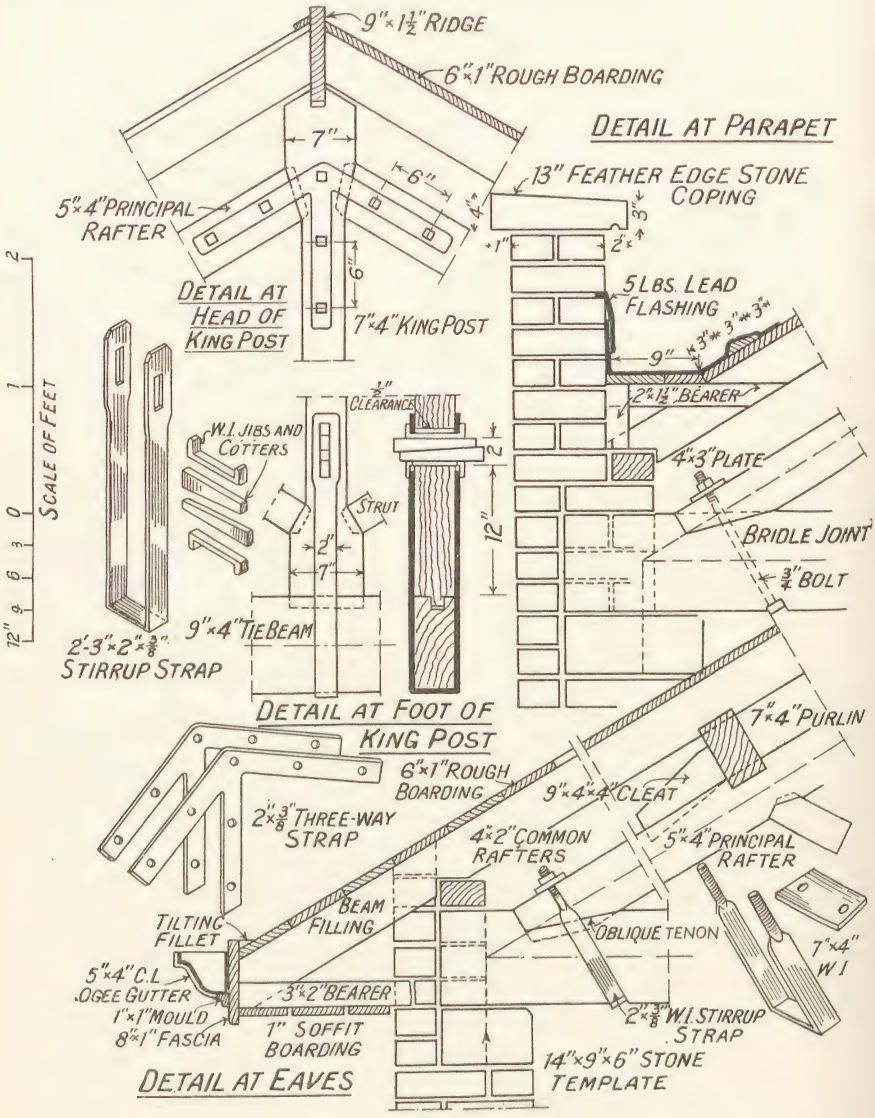


Fig. 2.—KING-POST DETAILS

Showing details at head and foot of king-post, eaves, and parapet.

two in number. The purlins are cogged or recessed about ½ in. or so, to fit over the principal rafters, and are fixed by nailing. They are further secured and supported by cleats to prevent them from turning over or slipping down. Details of joints are shown in Fig. 2.

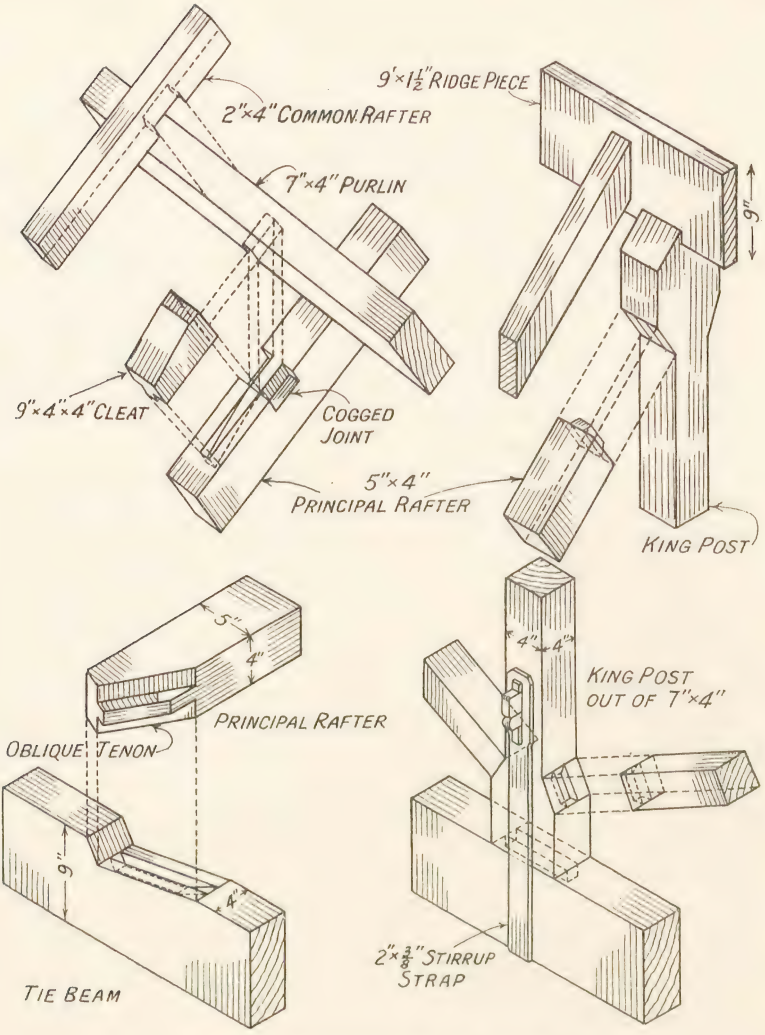


Fig. 3.—KING-POST TRUSS JOINTS

To form an abutment as nearly as possible at right angles to the inclination of the member, the king-post is reduced in size to about half its width in the middle, and to further secure the joints, iron straps are used (see Fig. 2).

Joints

The joint between the top of the principal rafter and the king-post is strengthened and made more secure with two three-way straps and

½-in. bolts, as shown. The joint between the king-post and the tie-beam is connected by a stirrup and tightened by folding wedges, sufficient clearance being allowed in both the stirrup and the post for this purpose (see Fig. 2). Heel-straps or bolts are used to hold the principal rafters to the tie-beam, and the principal rafter is formed by an oblique tenon or a bridle joint. Isometric sketches of the joints are shown in Fig. 3.

The trusses should be put together with the king-post slightly short, and the struts slightlyfull, to length. In small roofs what are known as *dragon beams* and angle ties are employed to prevent the outward thrust of the hip rafter from acting directly on the corner of the building (see Fig. 4).

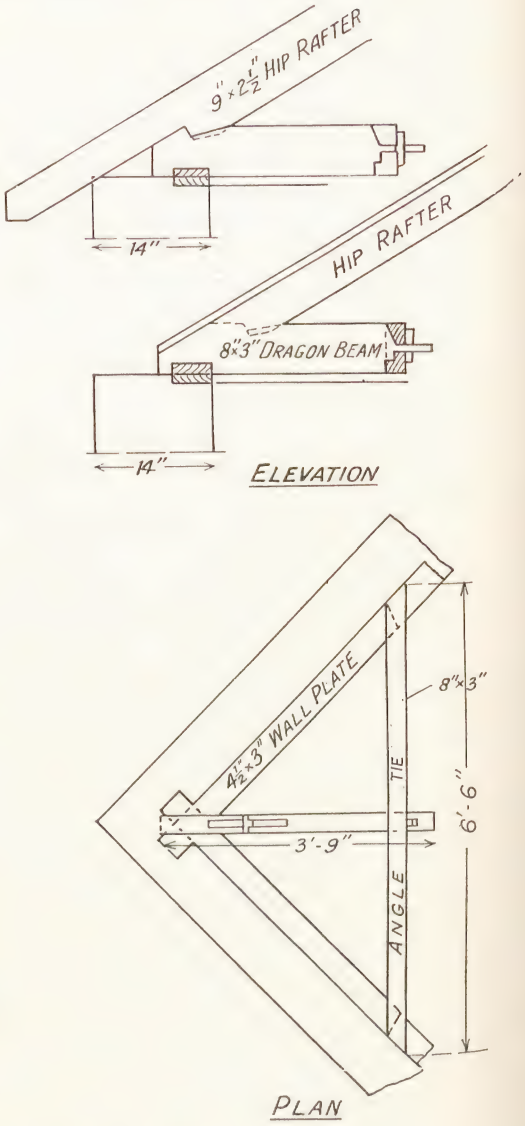


Fig. 4.—ANGLE TIE AND DRAGON BEAM

Sizes of Various Members

To find the sizes of the various members the following rules may be employed. For the thickness of all members, take ¼ span in feet — 1, = thickness in inches. The breadth of the members on the elevation will be : tie-beam, ½ span in feet — 2 ; centre of king-post, ⅙ span in feet. Make king-post ends twice width of centre less ½ in. ; struts 2 in. for 20 ft., increasing ¼ in. in width for every 2 ft. Reduce thickness of truss by ½ in. and depth of tie-beam by 1 in. if there is no ceiling.

CHIMNEYS AND FLUES

A SINGLE channel to carry off smoke is called a flue, and a number of these channels grouped together, a chimney stack. The internal divisions between the flues are usually 4½ in. thick, and are termed " withs " or "withes."

The entrance from the fireplace to the flue is known as the " mouth." A good open grate should be deeply recessed and incline forward at the top, having the sides and back formed wholly in fire-clay to provide a satisfactory heating surface. It is important to choose a stove by a maker of repute, with the sides and back scientifically shaped, for the heat immediately over the fire should be at a temperature higher than that of the ignition point of the fuel gases before they pass into the " mouth " above the grate.

Breast and Jambs

The walling containing the flue is called the chimney breast (Fig. 1). The chimney breast is carried up above the roof, and known as the chimney stack from the ceiling of the topmost room to the topmost point. The piers on either side of the fireplace opening supporting the chimney breast are termed jambs. Jambs must not be less than 9 in. wide, but as, more frequently than not, especially on upper floors, they contain flues, they are usually constructed 18 in. wide. Where jambs are 13½ in. or less, they must be tied together, and this is done by the cambered wrought-iron chimney bar, which supports the arch over the fireplace opening. This bar should be 2 in. or 2¼ in. by ¼ in., split at the ends, and turned up and down into the brickwork to give it a good hold.

Arches

Where the fireplace opening is less than 2 ft. 6 in. in width, the arch over it may be composed of one 4½-in. brick ring, but for all wider openings up to 3 ft. 6 in., a 9-in. arch should be used.

It is not always necessary to employ brick arches over the fireplace openings. Stone lintels are employed in districts where that material is suitable, and a York-stone slab 6 in. thick, perforated for the flue, forms a good covering, but precast reinforced-concrete lintels, specially adapted to the opening required, are being increasingly employed (Fig. 2). These are easily made on the site in moulds, and should be 6 in. thick by 18 in. back to front, and 4½ in. longer than the opening. They are reinforced with ⅜-in. steel rods hooked at the ends. In the centre of the

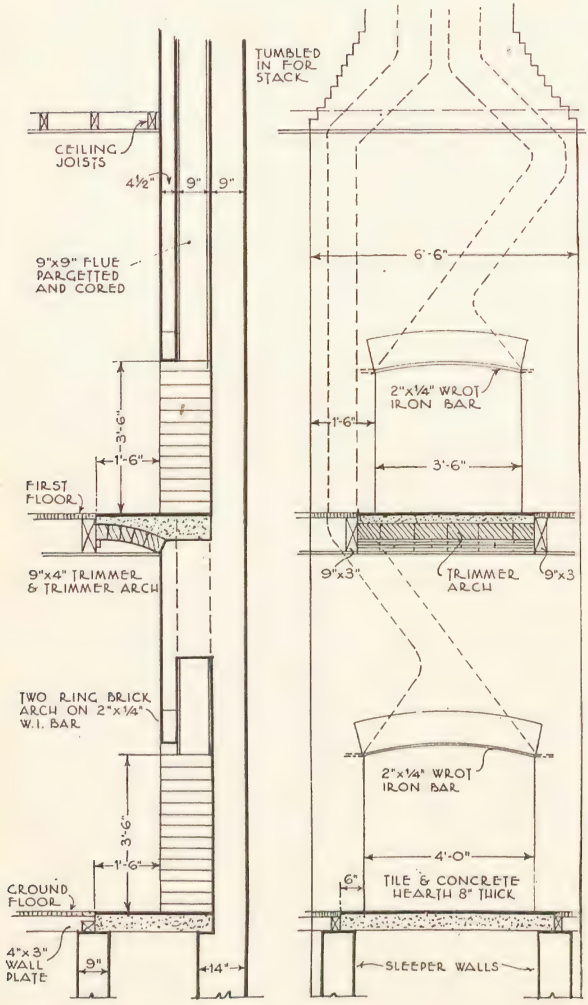


Fig. 1.—ELEVATION AND SECTION OF CHIMNEY BREAST

slab an opening is left for the flue, and it is a good practice to make the bottom of the hole 12 in. square, tapering to 9 in. at the top. The flue can be built straight up on the concrete slab without any gathering over, which materially simplifies the bricklaying and pargeting.

Hearth

The incombustible material which projects in front of the fireplace opening is called the front hearth. This must be 6 in. wider than the opening, and usually projects about 1 ft. 6 in. into the room. This front hearth generally continues back into the opening between the jambs, and is here called the back hearth.

The hearths on ground floors (Fig. 3) are carried on fender walls round their outer edges, which also provide support for the wood wall plates which take the floor joists. The space under the hearth is filled with solid hard core and rammed, or if the depth to the surface concrete under the floor is too great, the hearth may be composed either of a slab of reinforced concrete about 8 in. thick, or of stone flags. If the hearth is to be finished with tiles, these slabs must be kept sufficiently below the floor level to allow for the thickness of the tiles.

Trimmer Arches

On upper floors constructed of wood joists, a special trimmer arch is inserted under the hearth (Fig. 4). This consists of a 4½-in. semi-arch

of bricks springing from a skewback on the chimney breast, and bearing at its other side against a wood trimmer in the floor, which is usually a 9-in. by 4-in. joist. The end of the trimmer arch resting against this trimmer is still further supported on a fillet nailed along it immediately below the brick ring. The arch is then flushed up in concrete to the level of the hearth, or to as far below it as will allow for the hearth being tiled without projecting above the floor. The trimmer joist will extend the full width of the chimney breast, and be tusk-tenoned at its extremities into the trimming joists. At the wall end, the trimmer arch should be kept sufficiently above the ceiling level to allow a bearer to be inserted under it to take the laths of the plaster ceiling of the room below.

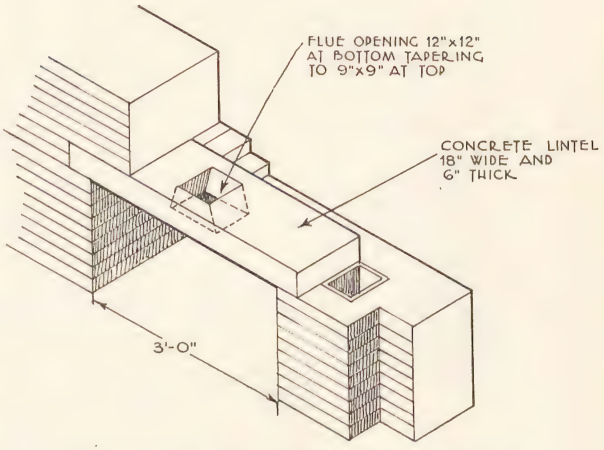


Fig. 2.—CONCRETE LINTEL IN PLACE OF ARCH

Lining and Pargeting

The internal openings of flues are lined with Portland cement from $\frac{1}{2}$ in. to $\frac{5}{8}$ in. in thickness, to give a smooth surface and prevent friction. The old method, known as pargeting, consisted of a lining composed of mortar and

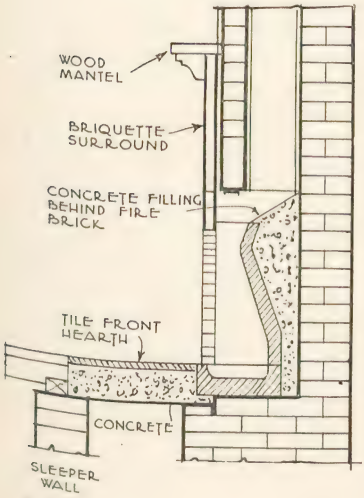


Fig. 3.—SETTING OF FIRE-BRICK OPENING

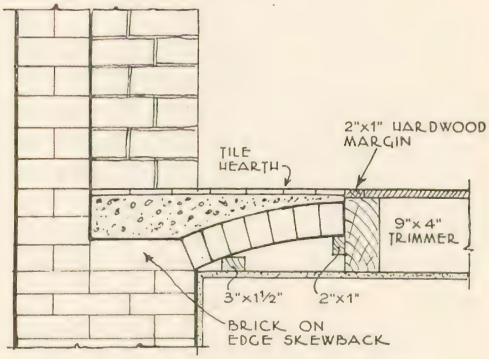


Fig. 4.—TRIMMER ARCH TO HEARTH

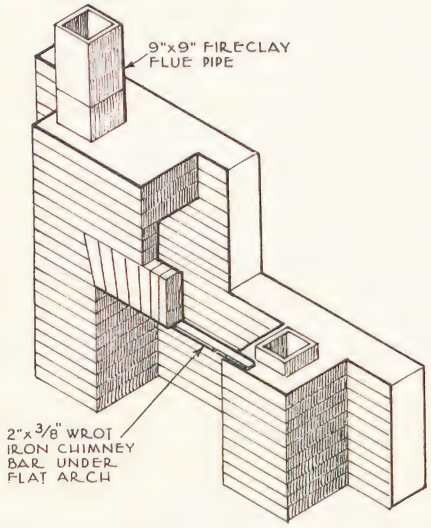


Fig. 5.—SHOWING GATHER OVER FLUE

cowdung in a proportion of 1 part of the former to 3 of the latter. The cowdung was added as a precaution against the mortar cracking with the heat.

Coring

Coring consists of keeping the inner faces of the flue free from mortar droppings and refuse, and the usual method is to attach a sack or bundle of hay to the end of a cord, which is gradually pulled up the flue as it is built.

Instead of rendering the inside of the flues with cement, or pargeting them, the whole may be constructed with fire-clay pipes (Fig. 5), either round or square in section. These pipes, usually about 9 in. in external diameter, and supplied in 2-ft. lengths, are slightly vitrified in the kilns and not highly glazed. They can either be inserted in straight flues, or be carried over for the bends by cutting the ends to mitre. Care should be taken to select the correct pipes, as high glazing produces too smooth an inner surface, which will cause constant small falls of soot.

This type of flue in brick chimney stacks eliminates the need for rendering, but in stone districts especially, where much rubble is employed, glazed fire-clay forms the only really satisfactory type of chimney and is economical to build, as the irregular spaces between the rubble and the pipes can be filled in with fine concrete.

Cracking of Stacks

For central-heating boilers the fire-clay pipes should always be used except in small domestic systems. It has been proved by the Building Research Station that sulphur compounds in the flue gases attack ordinary cement mortar lining to brick flues. When the boiler is damped down the temperature of the flue is reduced, and this allows a moisture deposit containing sulphur dioxide to attack the lining. This may produce considerable expansion with cement mortar, but is less violent where lime mortar has been employed. The decided leaning from the perpendicular noticeable in some flues is not always due to wind pressure, but may be produced by this chemical action.

Bends

Bends are usually provided in flues, and intended to check down draughts and the entry of rain or snow. With modern combustion

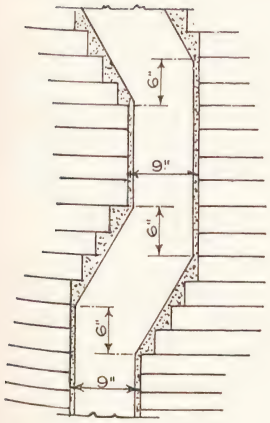


Fig. 6.—METHOD OF FORMING BENDS TO AVOID CONSTRICTION OF FLUE PASSAGE

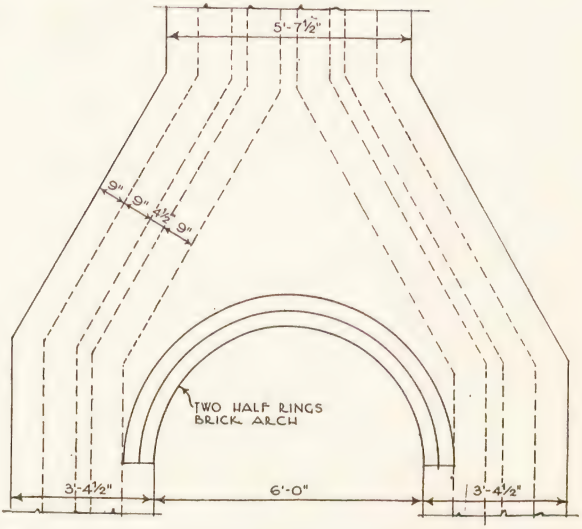


Fig. 7.—A METHOD OF GATHERING TWO STACKS INTO ONE

stoves they are not absolutely necessary, and form danger-spots where mortar and rubbish may accumulate when building a bend or, as it is sometimes called, a "cripple." Care must be taken to ensure that the sectional area of the flue is not contracted at this spot (Fig. 6). This is best done by carrying up the brickwork on the outer side of the bend two courses higher than on the inner. A slightly enlarged sectional area on the bend will result, which is not objectionable.

Gathering Over

Flues are said to be gathered over when collected from different parts of the building into one stack, a method adopted as much for economy as for appearance (Fig. 7).

Damp-proof Courses

To prevent wet that may penetrate the sides of the flue from soaking downward so as eventually to disfigure the wall below, it is advisable to insert a damp-proof course in the brickwork immediately above the roof level, turned up 1 in. on the inside and 1 in. downward on the outside of the stack. A damp patch appearing on the chimney breast of a room near the ceiling is usually caused either by the soaking down of wet in the brickwork, or from rain falling down the chimney pot to lodge at the highest bend of the flue, which is usually about ceiling level of the topmost room having a fireplace.

Arrangement of Fireplaces

Fireplaces may be arranged in several different manners to suit the plan or design, but it is always advisable to group as many as possible,

one stack being more economical to build than two ; one fire will also help another to burn well by keeping the flues warm, if they are near together.

Three usual methods are seen in Fig. 8. The first shows two angle fireplaces suitable for small rooms where most of the wall space is required for windows, doors, or furniture. Such fires satisfactorily warm the air but take up little space, having no projecting jambs.

Back-to-back Fires

The second drawing shows the common back-to-back method, which is the simplest and most usual in general building work. The chimney breasts are carried up together, and the jambs contain the flues. If the building is a tall one the jambs are corbelled out at the level of each floor sufficiently to take the 9-in. flue from the fireplace on the floor below. This is done first on one side of the fireplace and then on the other, until the top-floor fire may have jambs of considerable width.

Laced Fireplaces

The third method illustrated shows fireplaces laced together, a useful method of avoiding the projection at the chimney breast into rooms which are narrow in comparison with their length, or when the fireplaces are carried on steelwork on an upper floor, as in caretaker's quarters in banks and large office buildings, warmed in general by central-heating systems.

Gathering Over of Fireplace Openings

As the space occupied by the fire is considerably larger than the smoke flue, which is generally 9 in. by 9 in., the entrance above the fireplace arch has to be corbelled over in steps varying from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in. in each course (Fig. 9). This corbelling will not be equal on each side, for the flue will probably have to pass up one of the jambs of the fireplace on the floor above, which will pull the corbelling to one side as shown in the illustration.

Open Fireplaces

The large open fireplaces found in country districts seldom smoke if left alone, but the balance between up and down draught seems to have been arrived at so exactly through a process of trial and error that the slightest alteration will upset the flue altogether. The building of a new wing to an old house, the alteration of the chimney cap, even the changing of the position of the room door, have all been known to cause a big open-fireplace chimney to begin to smoke. Most of these chimneys were originally built to burn wood, and possess very subtle details which the modern builder either does not notice or deliberately omits, often with disastrous results.

The hearth is usually raised a few inches above the floor level of the room, and the height of the beam across the opening kept somewhere about 4 ft. 6 in. from the floor (Fig. 10). This beam is frequently splayed up on the inner side so that the lower edge above the fire forms almost a sharp point at the centre. The back of the opening, too, has a sinking about 2 ft. 6 in. wide, extending almost, but not quite, to the hearth itself. These small refinements met with in old work should be carefully observed in modern practice. Nevertheless, at times the smokiness of these old flues seems almost inevitable. Usually built projecting from an outside wall, with wide, bell-mouthed openings and straight flues (Fig. 10A), they encourage down draughts, but if a brick or metal canopy is constructed extending about 8 ft. up the flue mouth, or so far as is necessary to reach the narrow part of the chimney, a complete cure will frequently be effected. These canopies of

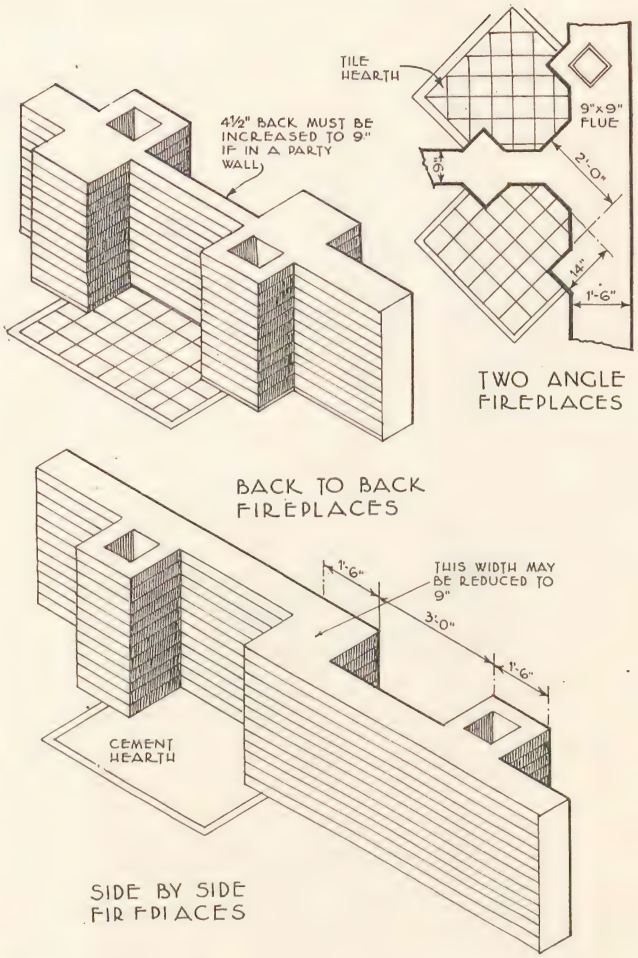


Fig. 8.—THREE USUAL ARRANGEMENTS FOR FIREPLACES

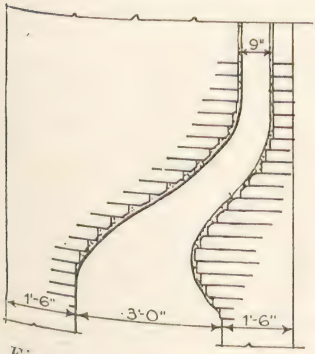


Fig. 9.—GATHERING OVER OF FLUE ABOVE FIREPLACE

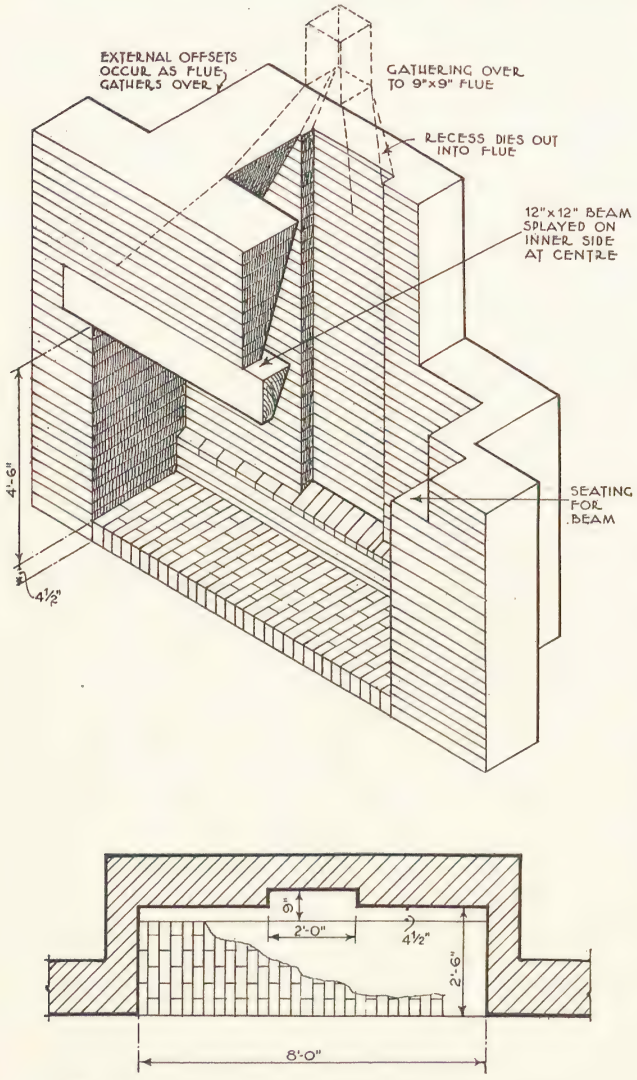


Fig. 10.—OPEN FIREPLACE WITH BRICK HEARTH

Note the small refinements in design, which should be carefully observed in modern practice.

brick or tile are usually constructed on a framework of wrought-iron bars built into the back of the fireplace, and have a better appearance than metal hoods.

Flue Damper

In a straight old flue it is often convenient to put, in the narrowest part, a damper, which can be closed during the summer, to prevent rain or soot droppings falling down when the fire is unlit.

Chimney Pots

The top of a chimney stack can be finished off in a variety of ways. The usual terminal is a terra-cotta chimney pot about $\frac{3}{4}$ in. thick, having a square base 9 in. in section, and tapering upwards to a circular form (Fig. 11). The pot stands within the brickwork at the top of the flue, and cement is weathered up to it and over the top of the stack. This is termed "flaunching." The top of the chimney should taper slightly, as this will increase the draught and help the smoke to escape.

In some cases where ornamental stacks are built, a short length of fire-clay pipe is inserted at the top, projecting only a few inches above

the flaunching, and quite invisible from the ground. This practice was not always followed in old work, with the result that a cold flue adjoining one with a fire was liable to siphon the smoke down into the room with the empty grate, usually a bedroom above (Fig. 11A). For this reason, whether pots are employed or not, the withs should always be carried up sufficiently high to prevent such suction.

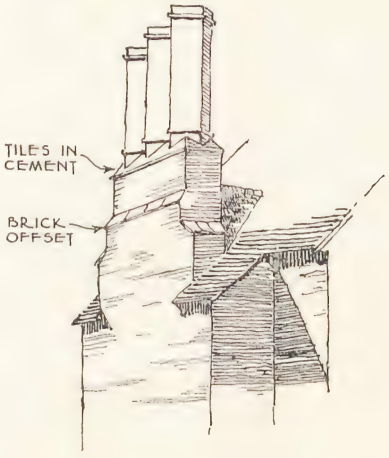


Fig. 12 shows a termination to a stack covered with a York-stone slab carried on the withs, and having sloping tiles built in at the sides. This type provides a good draught and is almost proof against down draughts, as well as protecting the flues themselves from rain and snow.

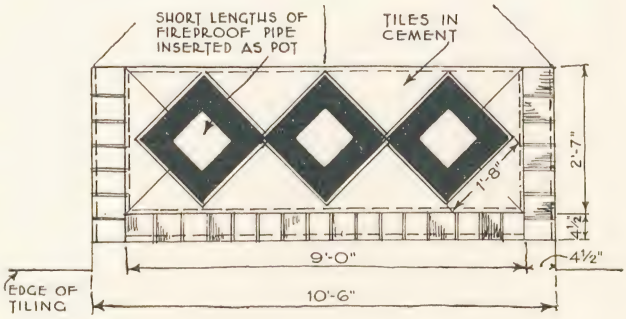


Fig. 10A.—ORNAMENTAL STACK
Showing plan of upper part of chimney stack.

Another, more elaborate type (Fig. 13), is found in some districts. This consists of building a brick tunnel over the flue projecting outwards beyond the edge of the stack, on corbels. Such a flue terminal must be arranged so as to be sideways to the prevailing wind.

One of the commonest ways of preventing or curing a down draught is the use of special pots, of which there are several on the market. The "Edwardian" pot (Fig. 14) has a dished top, which by deflecting the descending air currents prevents their entrance into the top of the flue, and four openings at the sides separated by wedge-shaped uprights. Whichever way the wind blows these uprights will ensure a good escape for the smoke, since they act as buffers on their flat windward sides, but allow the smoke to escape on the lee side. The sloping sides of the pot itself hold the air striking against it and turn it upwards, thus helping the smoke to escape. These pots are suitable for 9-in. square, or 11-in. round, flues. Where used for a 14-in. by 9-in. flue, this must first be squared at the top.

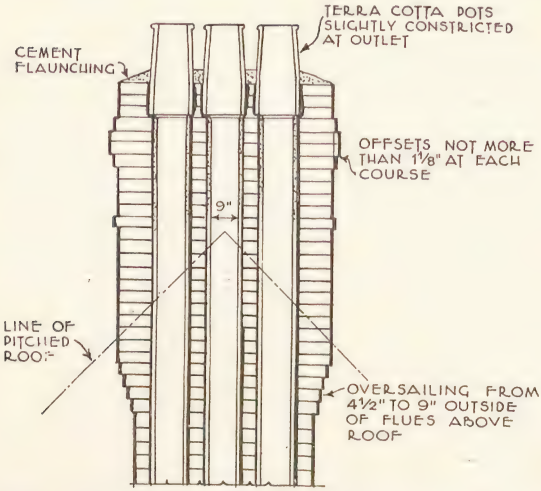


Fig. 11.—METHOD OF THICKENING STACK ABOVE ROOF

Another type (Fig. 15) has in the sides a series of louvres which act in much the same manner. The number of different cowls on the market is too numerous to describe, but it is perhaps as well to avoid one with moving parts if it is to be placed on a chimney difficult of access.

Brick Stacks

Many modern brick chimney stacks built with oversailing courses at the top look very clumsy, and the fault lies with a too great projection of the bricks. A projection of ¾ in. to 1 in. is sufficient for each course. This seems absurdly small when detailing the work, but it must be remembered that these oversailing courses are seen from below and on the angle, when their projections appear to be considerably greater than they are in reality (Fig. 16).

The Local Government Model By-laws

These are usually adopted by most urban district councils; their provisions with regard to chimneys and flues are definite, and may be summarised as follows :—

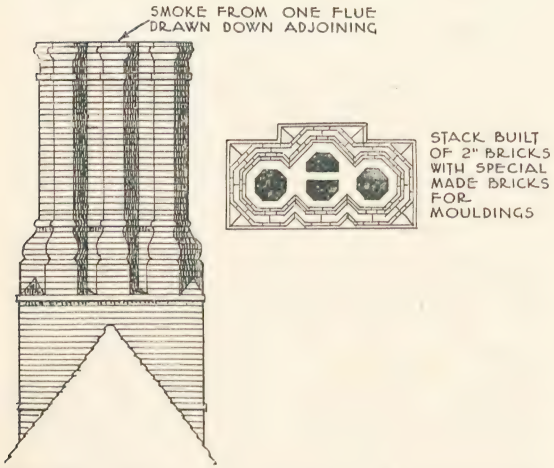


Fig. 11A.—PLAN AND ELEVATION OF ORNAMENTAL BRICK CHIMNEY

Construction of Flues

Flues must be constructed of brick or stone properly bonded and laid in cement or lime mortar, or of other suitable incombustible material properly put together. Every chimney must be bonded with the wall adjoining, and built, except in certain cases, on proper foundations and footings. The certain exceptions

include the construction of a flue supported on steel girders or on brick or stone corbelling, but no flue may be so corbelled out to a greater extent than the thickness of the wall.

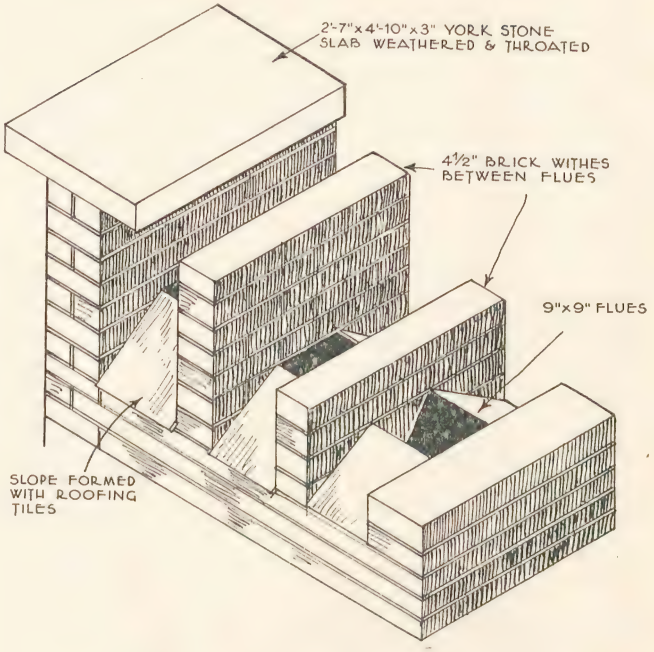


Fig. 12.—Finish of chimney stack without pots

Pargeting

All flues must be pargeted through their whole length, unless lined with fireproof pipes at least 1 in. thick. Factory and hotel flues must be built 9 in. thick for a distance of 10 ft. above the floor of the furnace or cooking range. Where the thickness of flues is less than 9 in., the outside must be rendered unless the face is constructed so as to form part of the outside face of the wall.

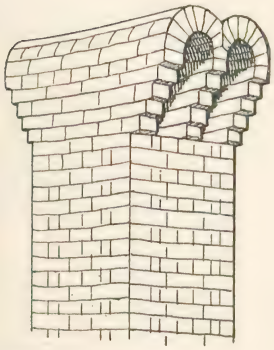


Fig. 13.—Flemish brick smoke baffle on stack

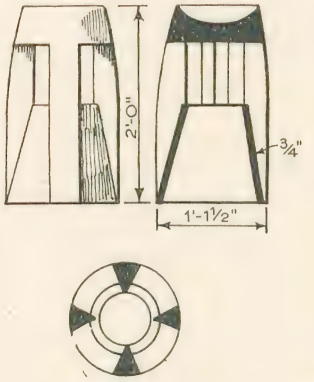


Fig. 14.—"Edwardian" chimney pot

Fig. 15.—Sankey chimney pot

Chimney Breasts

Chimney breasts must have a brick arch or stone or concrete lintel over the fireplace opening, and if the breast projects more than 4½ in. from the wall face, and the jambs are less than 14 in. wide, the opening must be tied in with a chimney bar 18 in. longer than the opening, and turned up and down at the extremities where it is built into the jambs on either side.

Jambs

Jambs to fireplaces should not be less than 9 in. wide on each side of the fireplace opening, and every flue must be surrounded with brick or stonework at least 4½ in. thick.

The backs of all fireplaces must be 9 in. thick unless fireplaces are built back to back, in which case they may be 4½ in. thick, and the back of the stove fixed in the opening must be built in solid so that there is no space between the back of the stove and the back of the opening.

Bends

Where the bend of a flue is more than 45° from the vertical, the brickwork surrounding it (or at least its upper side) must be 9 in. thick.

Height above Roof

Flues must be carried up in incombustible material at least 3 ft. above the roof or flat, measured from the highest point of the junction of the flue shaft and roof. (This height is not always the standard, as some authorities allow 2 ft. 6 in.)

No single chimney stack shall be carried higher than six times its least width without special arrangements being made properly to support it.

Timber near Flues

Timbers may not be built into a flue nearer than 9 in. to the inside, or within 10 in. of the upper surface of the hearth. Wood plugs must not be inserted within 6 in. of the withs, and iron holdfasts within 2 in. of the inside.

All external faces of flues within 2 in. of joinery must be 9 in. thick, or if of less thickness must be properly rendered. The hearth of a fireplace must be of incombustible material, 6 in. thick, extending 6 in. on each side of the opening, and projecting 16 in. in front of the chimney hearth. Hearths may not be sunk below the level of the floor of the room.

Tall Chimneys

Tall chimney shafts are governed by special regulations, and must be built on concrete foundations at least 18 in. thick and projecting 18 in. beyond the lowest course of footings, the base of the shaft to be in solid brickwork.

The narrowest external width from centre of one face to centre of opposite face must equal :–

For square shafts, $\frac{1}{10}$ of height.

For polygonal shafts, $\frac{1}{11}$ of height.

For circular shafts, $\frac{1}{12}$ of height.

Shafts shall have a batter of $2\frac{1}{2}$ in. for every 10 ft. in height. The thickness must be 9 in. at top and for 20 ft. below, and this thickness to be increased $4\frac{1}{2}$ in. for every additional 20 ft. down. In addition, the shaft must have an independent fire-brick lining for one-sixth of its height, with a 1-in. cavity between it and the brickwork, this cavity to be enclosed at the top with corbelled brickwork.

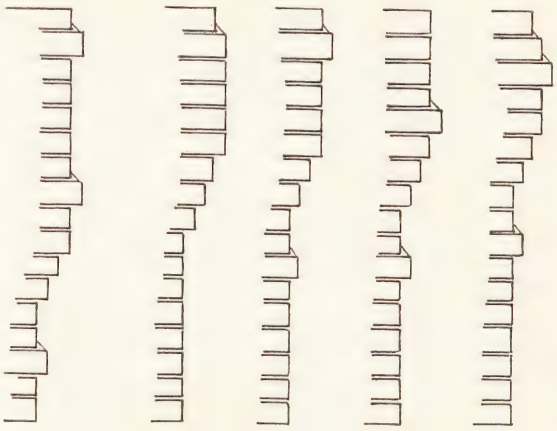


Fig. 16.—PROFILES OF BRICK CHIMNEY STACKS
Built in 2-in. bricks, projections $1\frac{1}{8}$ in. on face.

These regulations usually add that chimney shafts built in other manners will be considered, provided that their stability and suitability for their purposes are approved.

Gas Flues

Where gas fires are used as a permanent means of heating, substantial saving in the cost of building can be made by employing specially constructed gas flues in place of building up the usual 9-in. by 9-in. brick chimneys. These gas flues will not only save in the cost of brickwork, but also in foundation work, footings, trimming arches, and trimming joists, all of which may be omitted.

Pipe Flues

Small, glazed earthenware pipes have at times been used as gas flues, but apart from the difficulty of bonding circular pipes into the brickwork they have not proved entirely satisfactory in carrying off the products of combustion from a gas stove. A gas fire must never be ventilated into the cavity of a hollow wall without a proper flue being built for the purpose. The best type of flue is one formed of concrete blocks cast to sizes so as easily to bond with the brick wall, and having a flue with an internal dimension of 12 in. by 2 in. or 15 in. by $2\frac{1}{2}$ in.

Concrete Flues

Modern gas flues are readily obtainable in cast concrete, with the faces of the blocks heavily scored for plastering. They may be had in single or double blocks, the latter for use where flues are backing on to one another. These double blocks have a bed of 17 in. by 9 in. for bonding into a 9-in. wall, with a centre web between the two flue openings of 1 in. This narrow centre web allows the outer walls of the flue to be of extra thickness so as to give a wide bed for bonding.

Flue Blocks

The ordinary flue block is $16\frac{3}{4}$ in. in length, $4\frac{1}{2}$ in. wide, and 9 in. high. A double flue has similar dimensions, but a width of 9 in. in place of $4\frac{1}{2}$ in. The larger flue blocks for use with larger fires, i.e. those having more than seven and less than fifteen radiants, are $20\frac{1}{2}$ in. in length, the other dimensions remaining the same. The dimensions of the flue opening in all these blocks are approximately 6 to 1, which has been found by test to be the most suitable form for the removal of gas fumes.

The following Table shows the minimum sizes for different gas fires :—

Number of Radiants	*Minimum Flue Area*	*Floor Area of Rooms*
5 to 6 ..	20 sq. in. ..	100 sq. ft.
7 to 8 ..	24 sq. in. ..	150 sq. ft.
9 ..	30 sq. in. ..	200 sq. ft.
10 ..	36 sq. in. ..	250 sq. ft.

The flues should never terminate below the roof line or be poked out from the eaves, for in either case a heavy wind will cause down draught and blow the products of combustion back into the room. An entirely separate flue must be provided to each fireplace.

Terminal

The terminal should ensure the quick dispersion of the gases, and have the vent holes protected from driving rain or snow. Where they include more than one, these must be arranged to avoid the siphoning of the products from one flue to another.

For small fires, with less than eight radiants, special building-in sets providing an opening 2 ft. high are obtainable in the same material as the flues, but the space behind larger fires should be built in brickwork, gathered over to the slab above.

Keep Passage Free

In building up the concrete blocks of the flue, the passage, which is narrow, must be carefully kept free from mortar "fangs" projecting into the opening. A good method of doing this is to tie a piece of sacking to a string and draw it upwards through the flue as the blocks are fixed, keeping it always just below the top of the last block to be laid.

Types of Concrete Blocks

The blocks, which are delivered complete, are of different shapes, and the number of each required should be stated when ordering (Fig. 17).

These comprise :—

(1) The blocks which form a backing for a gas fire. Three blocks will give a height of 2 ft., and if a built-in type of fire is used this must be set so as to give at least 2 in. clear space at the back.

(2) The cover block which acts as a lintel over the opening.

(3) The standard straight blocks, each 9 in. deep, and arranged for bonding into the brickwork.

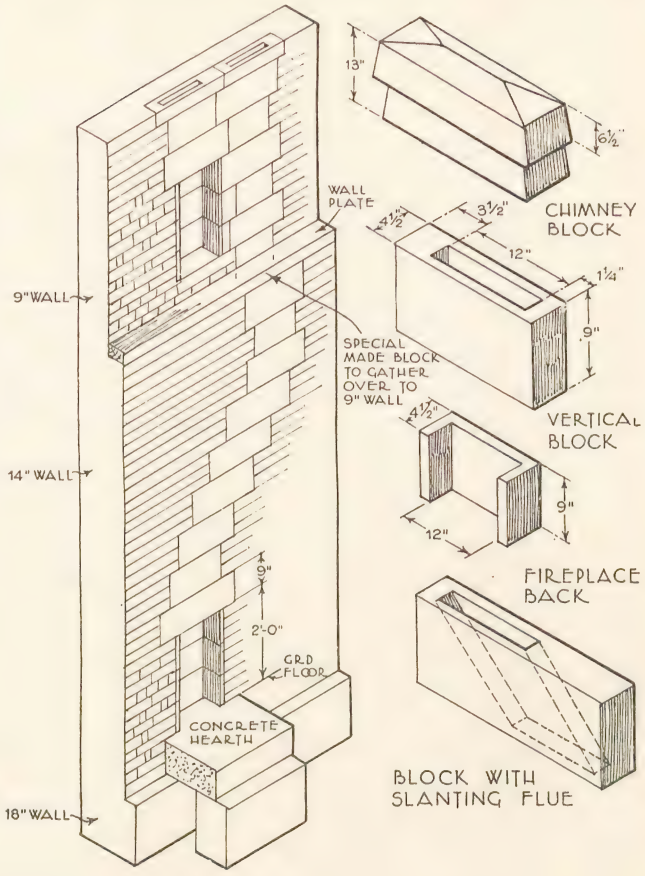


Fig. 17.—GAS-FIRE FLUE BLOCKS BUILT INTO WALL

(4) The raking blocks, which will give a bend of either 40° or 60° as required.

(5) The offset blocks, which enable the flue to be set back or forward 4½ in. to range with the decrease in thickness of the wall on upper storeys.

(6) The closer block, to give a straight edge when the flue appears above the roof, and to facilitate flashing.

(7) The corbel block, which allows the stack to be widened out enough to build a brick stack upon it, above the roof line if desired.

(8) The terminal, or pot, which caps the gas flue and prevents weather penetrating down the flue.

Gas flues have been approved by the Ministry of Health, the L.C.C., and most local authorities, and are suitable for all types of buildings, both domestic and industrial. Such flues can also be used for ordinary

ventilation intake or extract purposes, and being constructed of concrete will last indefinitely without attention, never requiring to be painted, which is a necessity with metal ventilators.

Theory of Flues

The theory of flues and the escape of smoke is based on the principle that air when heated expands, and increased volume diminishes in density. Thus hot air tends to rise, as it is less dense than the air of the normal atmosphere. The velocity with which heated air ascends may be expressed by the formula :—

$$V^2 = 2gh, \text{ where } g = 32, V = 8\sqrt{h}, \text{ and } h = Ht \times \cdot 002.$$

H = the height of the column of heated air in feet, and t = the excess of degrees Fahrenheit of heated air over the external air.

To find the velocity in a normal flue the method is as follows :—

The ordinary flue is 9 in. by 9 in. square, and, say, 30 ft. high. Therefore, by using the formulæ already mentioned, $V^2 = 2gh$ and $h = Ht \times \cdot 002$, we get, supposing the temperature difference to be 60° F.:—

$$h = 30 \times 60 \times \cdot 002,$$
$$h = 3 \cdot 6,$$
$$\therefore V^2 = 2 \times 32 \times 3 \cdot 6 = 230,$$

and V = 15 ft. per second approximately.

Now as the superficial area of the flue is 81 sq. in., and the velocity is 15 ft. per second,

$$\therefore \text{ the amount which passes up the flue is } \frac{15 \times 81}{144} \text{ or } 8 \cdot 4 \text{ cu. ft.}$$

To enlarge the flue above the point of entry will lower the velocity, and it is therefore important that the area of the flue should remain constant throughout its length to obtain the most satisfactory results. Once the flue has become heated the velocity is maintained, and the air in its ascent carries off the gaseous products of the fire. When the hot air reaches the top of the flue its velocity is converted into pressure, and if this pressure is less than the pressure of the atmosphere, the smoke will not escape, and in all probability will be converted into a down draught.

A good draught is obtained by having a free inlet which is not large enough to admit an excessive quantity of cold air. Bends should be as few as possible and never abrupt, and the exit should be slightly narrower than the flue itself, to increase the draught at the point of outlet to the open air.

The temperature at the throat to the grate, that is, the narrow entrance immediately above the fire into the chimney, should vary between 100° F., when the fire is lit, and 250° F., when it is burning brightly. If, however, the fire burns dead and there is a high temperature at the throat, it is a sign that there is a stoppage in the flue.

LINTELS AND BRESSUMMERS

LINTELS are horizontal members placed over openings to carry the weight of the upper walls and partitions. In such openings, which are filled in by the door and window frames at a later stage of the building, the lintel prevents the superimposed weight of the structure from taking a bearing on the joinery.

Bressummers perform the same function as lintels, but openings spanned by them are usually wider and not necessarily filled in with joinery. Both lintels and bressummers are, in fact, short beams carrying distributed loads, and are therefore subject to the same type of stresses and strains as are usually associated with joists, so that calculations to determine their dimensions are made by the same formulæ. But for practical purposes it is enough to remember in general that a lintel or a bressummer is subjected to a compressional strain in its upper half, and that below the centre line, or neutral axis, the fibres are always in tension.

By-laws Relating to Lintels and Bressummers

The usual clauses of the Model By-laws issued by urban councils and other local authorities specify that every wall over an opening in an external wall shall be properly and adequately supported by an arch or lintel of hard and fire-resisting material. Bressummers are required to have templates of stone, iron, terra-cotta, or vitrified stoneware the full breadth of the member, and also to have a bearing in the direction of their length of not less than 4 in. at each end.

Materials

Lintels may be composed of wood, stone, concrete, or steel. Cast-iron lintels are occasionally to be met with in some old buildings constructed during the first half of the last century, but these are now obsolete, and never employed in modern practice.

Cast-iron Lintels

In repairing or altering such a building, the cast-iron lintels are easily recognisable because the upper flange is considerably narrower in section than the lower. They also have projecting fins, along the face of the web, cast on at intervals and connecting the two flanges together, thus acting as stiffeners.

Lintels of More than One Material

In modern work, lintels are frequently formed of a combination of different materials. Thus a stone lintel is seldom carried right through

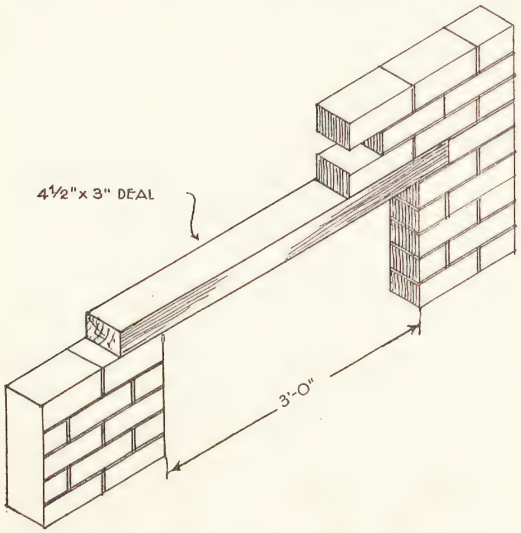


Fig. 1.—DEAL LINTEL IN BRICK PARTITION

the full thickness of the wall, but is backed with concrete, wood, or steel-joist sections.

WOOD LINTELS

Wood lintels, where employed over small openings, are usually made strong enough to carry the superimposed load without assistance. Their depth may be calculated by the same methods as for wood beams and joists, but in common practice the sizes of timbers required for the convenience of bonding will be more than those theoretically sufficient for the load.

Thus a 4½-in. by 3-in. deal (Fig. 1), laid with the 3-in. side vertically, will carry a 4½-in. partition across a 3-ft. opening, and at the same time bond with the brick courses if the partition is of that material. In fact, any opening up to, say, 6 ft. in a domestic building may be safely spanned by three 6-in. by 3-in. joists spiked together, which will support the weight of a 9-in. solid, or 11-in. hollow, wall. It should always be remembered that the actual weight of brickwork carried by the lintel is that contained within an equilateral triangle having as a base the width of the opening spanned. By the natural cantilever arrangement of the construction of a brick wall, the weight of the structure outside the sides of the triangle is transferred to the abutments.

Relieving Arches

Where a wood lintel is employed in conjunction with a brick relieving arch (Fig 2), the scantling of the former can be considerably reduced even for quite wide spans, since the arch will throw off the weight on either side on to the solid brick piers, and the lintel will have to bear only its own weight and the load of the brick or tile infilling between the intrados of the arch and the top of the lintel. An arch thus constructed to relieve the lintel must have its abutments clear of the ends of the latter ; the skewbacks should therefore be sloped outward, and away from the top edges of the lintel ends.

The bearing of the lintel on the wall will be about 4½ in. at either extremity, and the span of the relieving arch will thus be 9 in. more than that of the opening. Such arches are usually constructed of two half-

brick rings with a rise of about 6 in. at the centre, and a thickness equal to that of the lintel below.

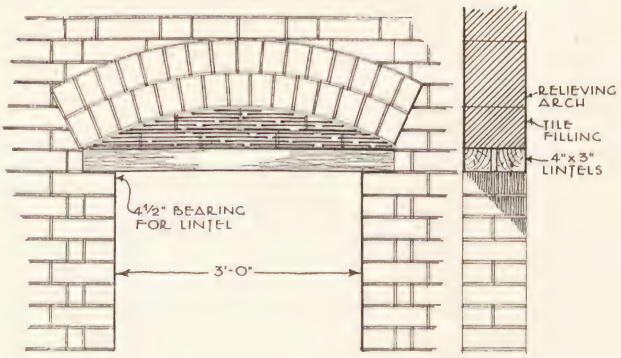


Fig. 2.—WOOD LINTEL WITH RELIEVING ARCH

Protection from Settlement

One advantage of this type of construction is that it protects the joinery from any undue settlement of the building produced by loads on the floors or walls above, and a further one is that should the wood lintel itself become decayed or unsound, it can be readily removed and renewed without affecting the stability of the building.

Built-up Lintels

Wood lintels can also be built up economically to obtain the spread necessary to carry the wall over, without being formed of a solid mass of timber. Fig. 3 shows a lintel composed of two 6-in. by 2-in. joists separated by 4-in. by 2-in. distance-pieces. These distance-pieces are bored and bolted through with ½-in. bolts, and are placed at intervals of about 5 in. along the length of the lintel. This construction forms a strong and sufficient support in a 9-in. wall over ordinary door and window openings. The same type of construction, using deeper joists, will carry over wider spans provided that the distance-pieces are carefully cut and fitted. It is important that these blocks be cut dead square on the ends, so that when bolted up the bolts will draw their ends evenly against the sides of the joists for their full depth. Inaccurate cutting will tend to twist the joists, and thus render the stiffeners worse than useless.

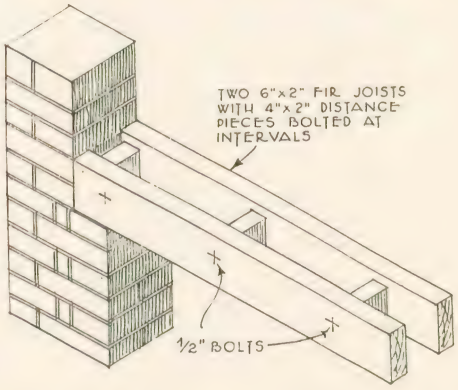


Fig. 3.—BUILT-UP LINTEL WITH DISTANCE-BLOCKS

Fixing Joinery

Wood lintels present an easy and economical means of

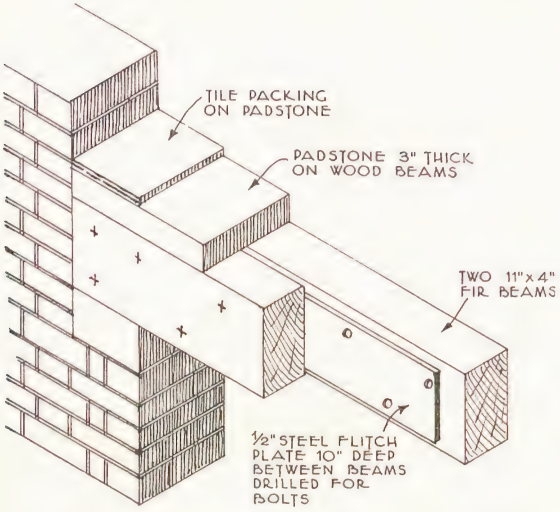


Fig. 4.—FLITCHED BRESSUMMER OVER WIDE OPENING

attaching the heads of windows and door frames, without resorting to plugging and other devices.

Flitched Bressummers

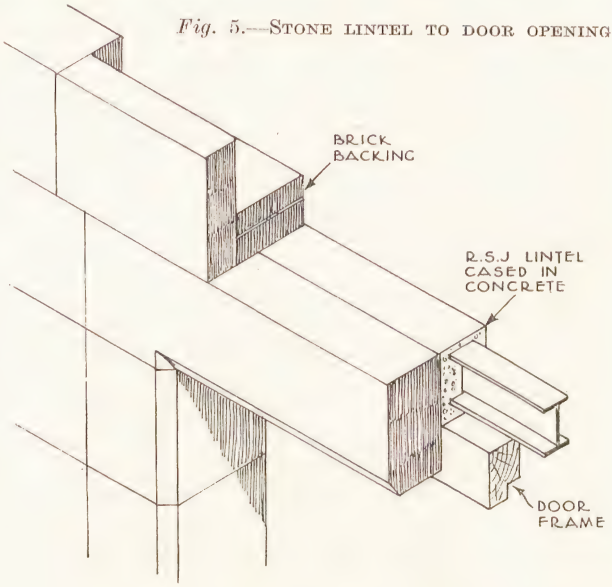
As these members are required to span considerably wider openings than lintels, they are composed of heavier timbers. Bressummer timbers are frequently placed side by side over an opening, with their longest sectional dimensions arranged vertically, and the whole secured together by bolts. Such beams are termed flitched bressummers. The bolts, for all practical purposes, should be placed along the centre of the side of the flitch, and in no case should a bolt hole be drilled nearer to the top or bottom edge than one-sixth of the total depth of the beam. Some theorists advocate the drilling of the bolt holes in the upper or compressional half of the member, to avoid weakening the bressummer by boring through the wood fibres that may be stressed in tension. But as the strength of a bressummer depends upon the different sections composing it being so tightly united that there is no fear of any one beam slipping under the load, the drilling of the bolt holes along the centre line is the most satisfactory method of ensuring this. The bolts generally used are $\frac{5}{8}$ in. in diameter, and secured with suitable washers on both sides of the flitch. A bressummer so built up may be calculated when designing it as a solid balk of timber capable of carrying the loads that could be safely borne by a single beam of the same sectional area.

Steel Flitches

This type of bressummer (Fig. 4) is less popular to-day than formerly, and although occasionally to be met with, is being displaced by the steel girder. It consists of thin steel plates, about $\frac{1}{2}$ in. thick, bolted between two or more beams. The bolt holes in this case should be disposed diagonally, part in the upper and part in the lower half of the beam, but never nearer to the edges than was allowed in the wood flitches already described. The steel plates should be about $\frac{1}{2}$ in. less in depth at the top and bottom than the beams which sandwich them, in order to avoid any chance of the steel projecting below the edges of the wood and riding on

the bearing. When this occurs, the stone templates have frequently been found to crack under the load transmitted to them on so narrow an edge.

Fig. 5.—STONE LINTEL TO DOOR OPENING



STONE LINTELS

As stone is a material of weak tensional stress, it is not suitable for lintels except over openings of small span. The ancient world overcame this weakness by using stone lintels of enormous thickness, but even then the openings were comparatively narrow. In modern practice, single-stone lintels may be used over doorways and window openings not exceeding about 4 ft. in width. Such a space can be spanned by a lintel of 9 in. deep, having a bearing of from 4 in. to 6 in. at either end. Spans wider than this will frequently crack, through the unequal settlement of the jambs.

Facing Lintels

Many stone lintels are employed only as facings (Fig. 5), their thickness being between 4 in. and 7 in., the remaining depth of the wall being supported by a reinforced-concrete beam or steel joist inserted behind the stonework.

Joggled Joints

Longer spans may be bridged by using what is termed a joggle-jointed lintel. This is, in point of fact, a flat arch, with the joints between the voussoirs cut by the mason in such a manner as to prevent the possibility of one stone slipping out of place.

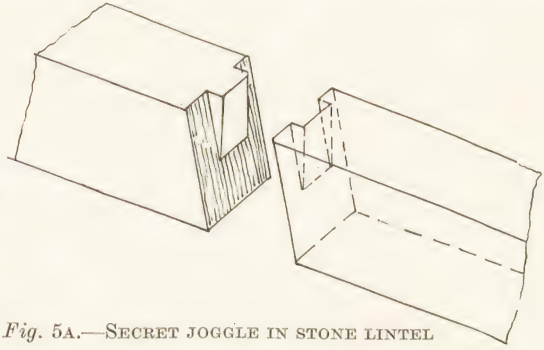


Fig. 5A.—SECRET JOGGLE IN STONE LINTEL

Sometimes the joggles are cut so as to show on the face, at others they

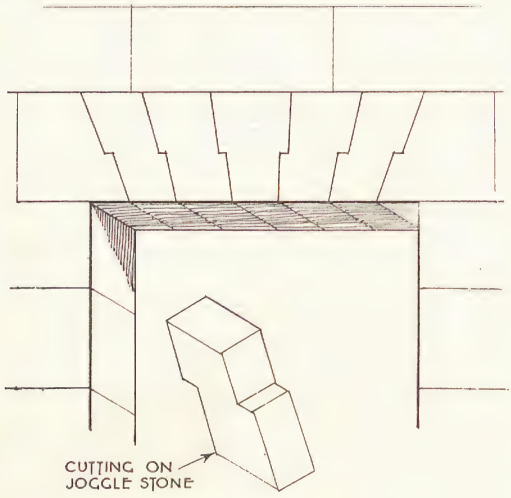


Fig. 6.—JOGGLED STONE LINTEL

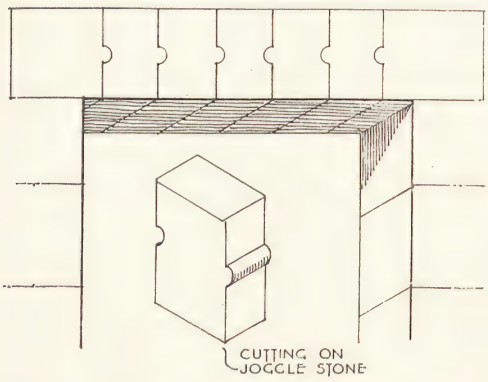


Fig. 7.—ANOTHER TYPE OF JOGGLED STONE LINTEL

are concealed, the face showing only a vertical joint (Fig. 5A). This latter method is termed a secret joggle.

Joggled lintels must be built up on a flat centering, which is removed when the last stone is in place and the ends of the lintel properly secured against tipping. It will be seen that the lintel (Fig. 6) is built up, beginning at the extremities and working towards the centre of the opening, in a similar manner to arch construction, while the lintel (in Fig. 7) is begun by placing the centre stone in position first, and working outwards towards the ends.

Jointed Lintels

In Gothic and Tudor type work, the lintels are frequently jointed over the centre of the stone mullions (Fig. 8). This is a good practice, as it allows long windows to be built without fear of the lintels cracking, for the joints will take up any uneven settlements that may occur. In old work it is very seldom that a lintel so constructed is found to be defective, although the window itself may be much deformed in shape owing to uneven settlement on weak foundations.

CONCRETE LINTELS

A simple, rough-and-ready reinforced-concrete lintel can be made with three lengths of $1\frac{1}{2}$-in. by $1\frac{1}{2}$-in. by $\frac{1}{4}$-in. T-iron laid with the T head downward. The Ts are cast into the bottom half of the concrete slab, as this is the portion of the concrete which is in tension when in position. Such a lintel, 6 in. in thickness, can be precast in a rough boxing on the site, and would be suitable for a 4-ft. to 5-ft. opening in a 14-in. wall.

When lintels are reinforced with rods (Fig. 9), these should be bent

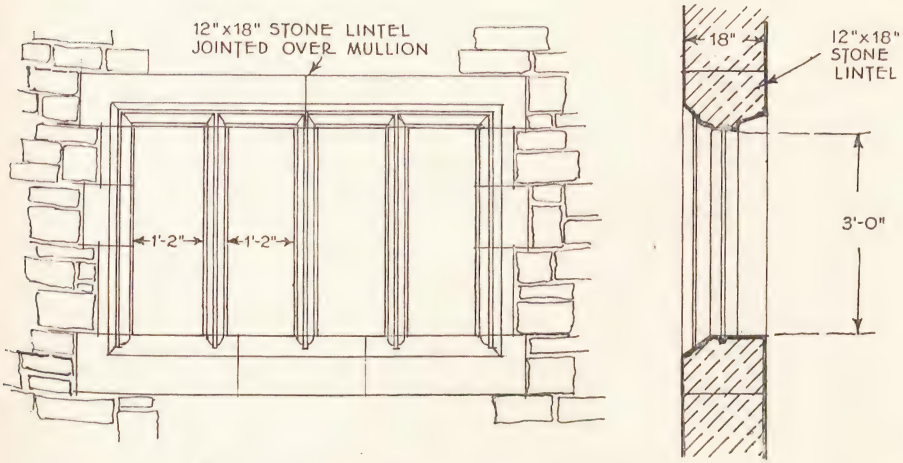


Fig. 8.—STONE LINTEL JOINTED OVER MULLION

into hooks at the extremities, and the ends of the outer rods bent up for about a quarter of the length of the lintel at each end. This reinforcement is required in the upper part of the lintel at these points, because the stresses under load resemble in some degree those on a concrete beam with fixed ends.

Stirrup Irons in Lintels

Normally, stirrups are not employed in small lintels, but if the wall is very thick or the lintel a long one, $\frac{1}{4}$-in. stirrups may be placed with advantage at distances of 9 in. along the two outer rods.

Sizes of Concrete Lintels

For spans up to 5 ft., $\frac{3}{8}$-in. diameter rods should be used, and they should be employed as follows :—

Lintel	$4\frac{1}{2}$	in. wide,	2	rods.
,,	9	,,	,,	3	,,
,,	14	,,	,,	4	,,
,,	18	,,	,,	5	,,

For spans over 5 ft. and up to 9 ft., rods $\frac{1}{2}$ in. in diameter should be used, the number of rods to the thickness being the same as before.

Openings 3 ft. wide should have lintels 6 in. in depth, with a $4\frac{1}{2}$-in. bearing at each end.

Openings between 3 ft. and 6 ft. wide require the lintel to be 9 in. deep with a $6\frac{1}{2}$-in. bearing, and openings over 6 ft. wide need a 12-in.-deep lintel with a 9-in. bearing.

Wider spans than these should be calculated as for loaded beams having a distributed load, and designed accordingly.

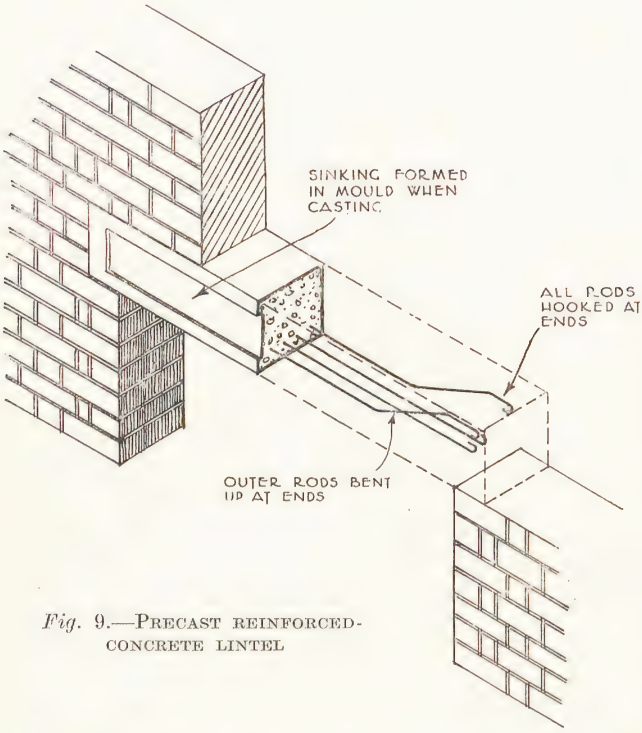


Fig. 9.—PRECAST REINFORCED-CONCRETE LINTEL

Precast Lintels

Concrete lintels may be either precast, or cast in position. In both methods the concrete employed should be composed of 1 part Portland cement, 2 parts of sand, and 4 parts of small aggregate, gauged and mixed as for normal reinforced-concrete constructional work.

When lintels are precast, whether on the job or at the works, it is a good practice to arrange for two $\frac{3}{8}$-in. lifting hooks, made of stirrup iron bent into the shape of a hairpin with the ends turned outward, to be fixed so that the loop end is flush with the top of the beam. Before the mix has set the space round the head of the loop should be cleared, so that when the lintels are being hoisted into position the work may be helped by a tackle, which is preferable to raising the lintels in slings or by hand.

Lintels Cast on the Spot

To cast concrete lintels in place, a shuttering must be erected round the opening, supported either by struts from the cill below, or on bearers resting in holes in the reveals left for the purpose, these being afterwards filled in with brickwork in a manner similar to the filling of scaffold putlog holes. Besides a soffit board, both front and back boards will be needed if the lintel goes right through the thickness of the wall. The soffit board should be cut exactly to fill the opening, leaving the concrete mix to be poured directly upon the portions of the jambs where the lintel will take its bearing. But the vertical boarding must extend the full length of the proposed lintel, including the supported portions at either end, and is best secured by being nailed to the main wall at either side.

When the concrete lintel is to be employed as a backing to a stone or brick lintel, the latter is first constructed, and the formwork then built

up to it, only a soffit and a back vertical board being required to complete the mould. The joint between the soffit board and the front lintel is stopped with clay.

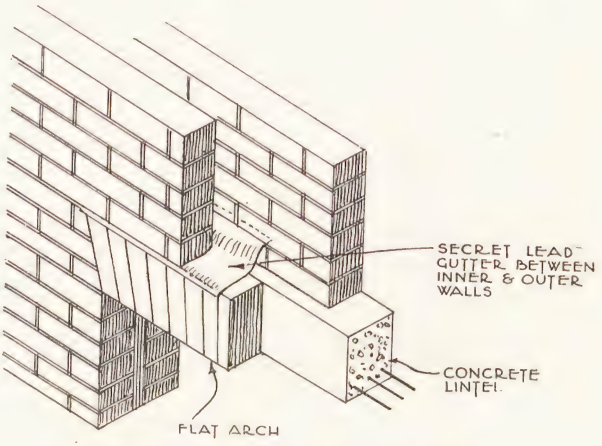


Fig. 10.—Lintel in hollow wall

Lintels in Cavity Walls

When lintels occur over openings in cavity walls (Fig. 10), a special arrangement must be made to carry away any water that may penetrate the outer wall face.

This is done by forming a secret gutter over the cavity with 4-lb. or 5-lb. lead, so laid that it throws any drippings away from the inner skin of the wall.

ROLLED-STEEL-JOIST LINTELS

One of the most useful types of lintel is that formed by using sections of rolled-steel joists, either singly, or in several lengths laid parallel, according to the thickness of the wall.

Lintels for Small Openings

For small openings it will not be necessary to make any calculations, the important point being to have a sufficient bearing width under the wall above ; all that is necessary is to ascertain from the list of British Standard Sections that the section of joist chosen is not below the deflection line (Fig. 11). Larger openings, such as the lintel to carry a wall over the span of a bay window, should be calculated in a precisely similar manner to that adopted for determining the strength of ordinary floor beams.

Rolled-steel-joist Separators

When two or three sections are joined together they should have separators between to keep them accurately spaced apart. These separators or distance-pieces may be composed either of sections of steam barrel large enough to pass the bolt through (Fig. 12), or of specially manufactured cast-iron sections.

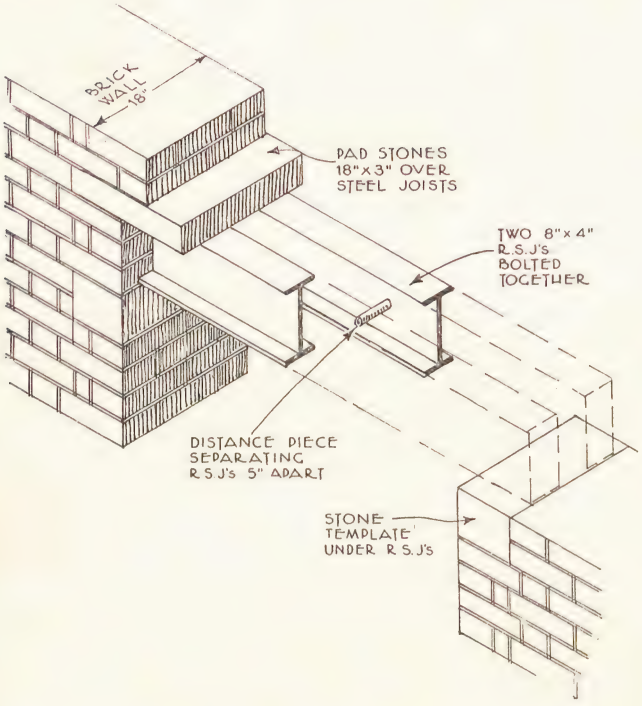


Fig. 11.—STEEL-JOIST LINTEL OVER DOOR OPENING

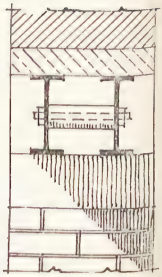


Fig. 12.—R.S.J.s SEPARATED BY BARREL DISTANCE-PIECE AND $\frac{5}{8}$-IN. BOLTS

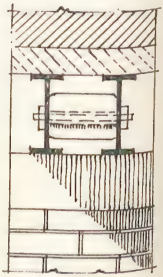


Fig. 13.—R.S.J.s SEPARATED BY CAST-IRON SEPARATOR AND $\frac{5}{8}$-IN. BOLT

Cast-iron Separators

These latter have a hole in the middle to take the bolt, and are continued as a fin both above and below. This fin is screwed up tightly to the web of the joists, and acts as a stiffener. A $\frac{5}{8}$-in. bolt will be found sufficiently large for bolting together two or three lengths of steel joist, if these are placed about 5 in. apart (Fig. 13).

Pad-stones on Lintels

The steel-joist lintel need not be the full thickness of the wall above, provided it is covered with a 3-in.-thick pad-stone. Thus, two 8-in. by 4-in. joists, separated 5 in. apart with distance-pieces, have an upper surface of 13 in., and an 18-in. by 3-in. pad-stone on this lintel will allow an 18-in. brick wall to be built upon it.

Stone Templates

Stone templates should be built in under all steel-joist lintels, in order to spread the bearing of the flanges right across the wall.

Lintels Best Cased in Concrete

Steel lintels may be left exposed provided that they are periodically painted, but it is a common practice to case the steel with concrete. When this is done, care must be taken to tamp the mix well down into the crevices between the joist sections and round the separators, to ensure that no part of the steel remains exposed to the air.

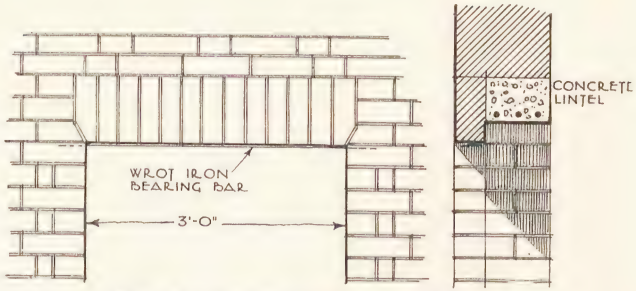


Fig. 14.—Brick and concrete lintel

FLAT-BRICK AND JOGGLED-BRICK LINTELS

The openings over doors and windows in a brick-faced building are sometimes spanned by a flat arch or lintel of similar bricks to the rest of the walling. Such lintels require care in construction, and certain additional measures taken to ensure their stability. Fig. 14 shows this type of flat-brick arch over an ordinary 3-ft. window opening. The lintel is 9 in. deep, and supported partly by a 2-in. by $\frac{7}{8}$-in. flat wrought-iron bar which is turned up and down at the ends, and pinned into the brickwork of the jambs on either side. A small 2-in. by 2-in. angle iron is sometimes substituted for the flat bar, and this is placed so as to support the inner bottom edge of the bricks. This shape is in some ways better than the bar, as the extra stiffness prevents any tendency to sag in the middle, but the fitting of the window frame into the reveal of the window is more difficult, as a certain amount of cutting at the head may be necessary. It is a good practice to cut a splay on the end bricks, as shown. A lintel is shown in Fig. 15 in which the bricks are frogged. Holes are drilled in the top edge of the bricks after they have been placed in position on the centering.

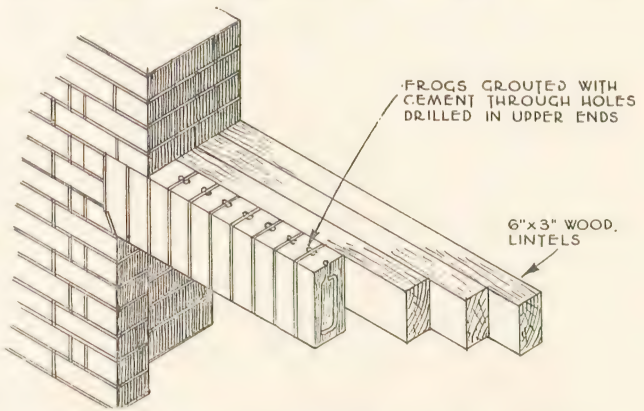


Fig. 15.—Joggled or soldier arch brick lintel

ROOF CONSTRUCTION

PART IV.—OBTAINING ROOF BEVELS—CALCULATING ECONOMICAL SPACING OF RAFTERS AND SAFE LOADS ON BEAMS—STRESS DIAGRAMS FOR ROOF TRUSSES—QUEEN-POST AND COMPOSITE ROOF TRUSSES—MANSARD ROOF

ROOF BEVELS

TO obtain the roof bevels for a span roof first draw a plan of the roof, as shown in Fig. 1. The bevels for the members may then be obtained as follows :—

Common Rafter

The bevels and lengths may be obtained direct from the section FLH, FH being the rise or height of the roof (Fig. 1).

Hip Rafter

At right angles to the plan of the hip, as AE or ED, set out height of ridge E_1 E_1, that is, the top point of the rafter. Join E_1A or E_1D : then the bevels are obtained as shown. For backing the hip, draw the line 1—2 at right angles to the plan of the hip, and at the point of intersection of these two lines draw the line 3—4 at right angles to AE_1. Rotate 3—4 down to 3—5, and join 1—5, 5—2, and the backing is obtained. A similar construction gives the length, bevels, and backing for the adjacent hip, which is, of course, different owing to the irregular shape of the hipped end.

Jack Rafter

From the true length of the common rafter LH, turn over line to position LF_1. Next produce line of jack rafter as shown at GG_{11}, then top bevel is at G_{11}. The side bevel will be as for the common rafter.

Roof Boarding

Find development of side and end slopes by turning F_1 to F_{11} and drawing $F_{11}E_{11}$ parallel to CD. A complete roof plan is shown in Fig. 2.

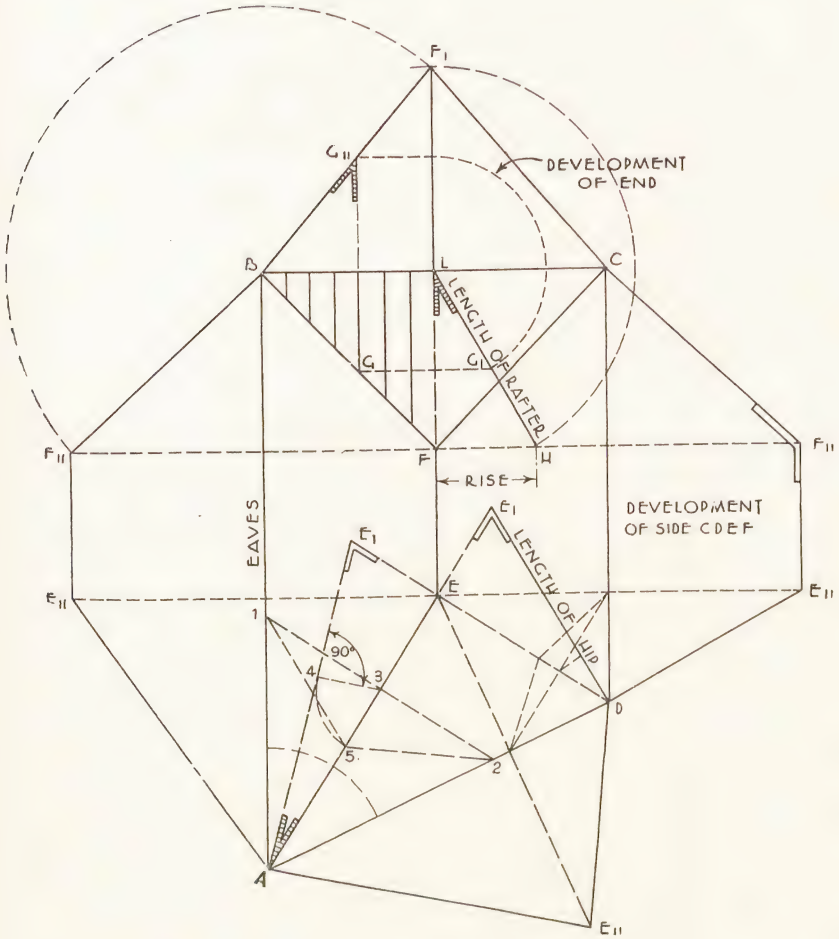


Fig. 1.—THIS ILLUSTRATES THE METHOD OF OBTAINING ROOF BEVELS

A plan of the roof is first drawn. The bevels of the members may then be obtained as described in the text.

Purlins

The bevels for the purlins are shown in Fig. 3. Set up the pitch of the roof, in this case 30°, and draw the plan of the hip at 45°. Place the purlin in position, and letter the points ABC. With B as centre, and radius BA, turn A into a horizontal position A^1. Next drop verticals from A, A^1 on to the plan of the hip as shown, and join A^1A^{11} horizontally. The line drawn through B^1A^{11} gives the top cut for the purlin. The side is obtained in a similar manner.

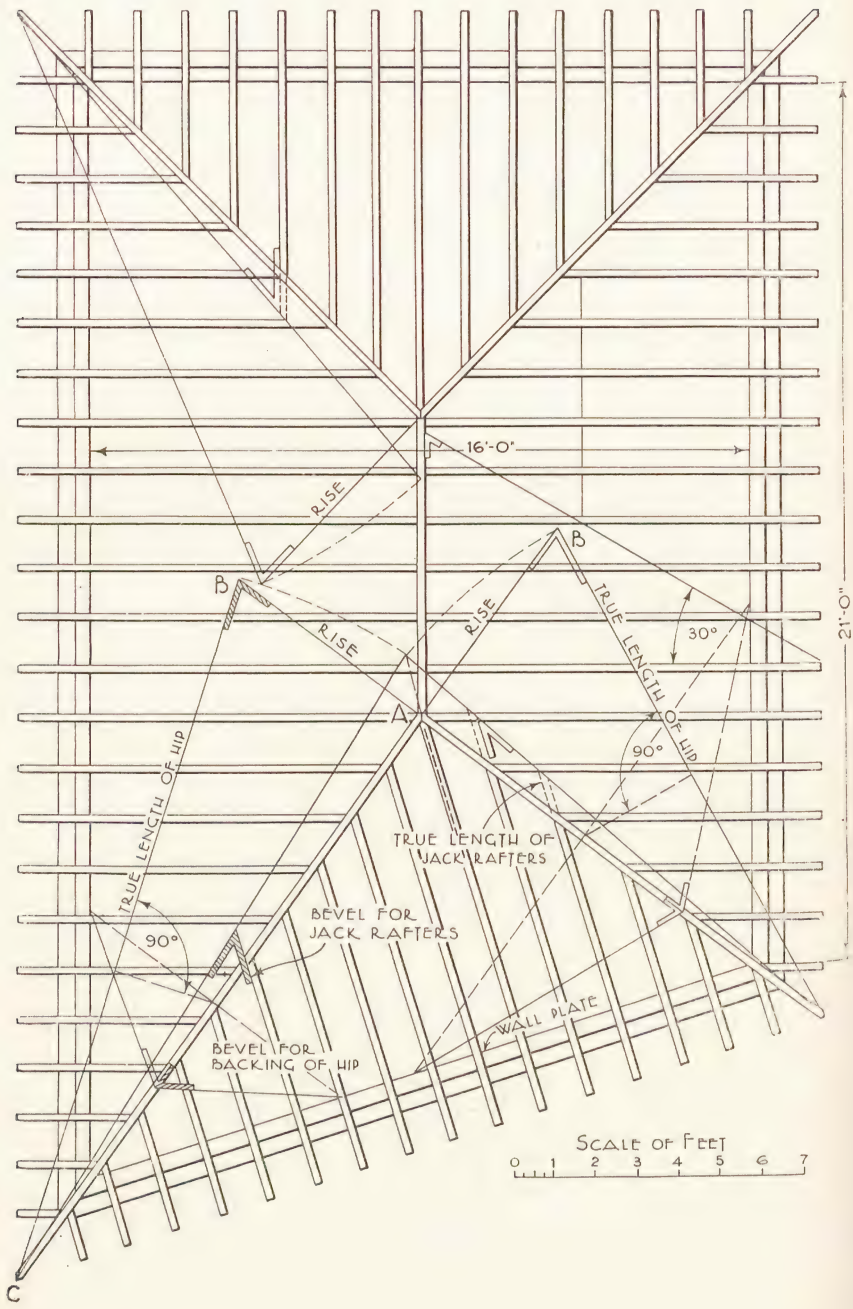


Fig. 2.—PLAN OF ROOF WITH IRREGULAR HIP END

Where Wall Plates Are at Obtuse or Acute Angles

Where the wall plates are at obtuse or acute angles, and the hips do not bisect the angle between them, the finding of the bevels will be slightly different, though based on the same geometrical principles (see Fig. 4). Draw lines ABC to represent the lines of the wall plates, and BD the centre line of the hip. Fix upon any point in it and draw IE, IC parallel to BC, AB respectively. At any convenient point E draw E2 at right angles to BC, and (2) draw 2–3 at right angles to E2. From E set up the pitch of the roof, and 2—4 at right angles to 2C. Make 2—4 equal to 2—3; joining C4 should give the pitch of that side of the roof; continue the lines 4C and 3E, and set out the sections and plans as shown in Fig. 4. Then with E as centre and 5 and 6 as radii, obtain the points 7 and 8; projecting down from these points, parallel to CB, points 10 and 11 are obtained, and thus the bevels FG. The bevels for the other side are obtained in a similar manner.

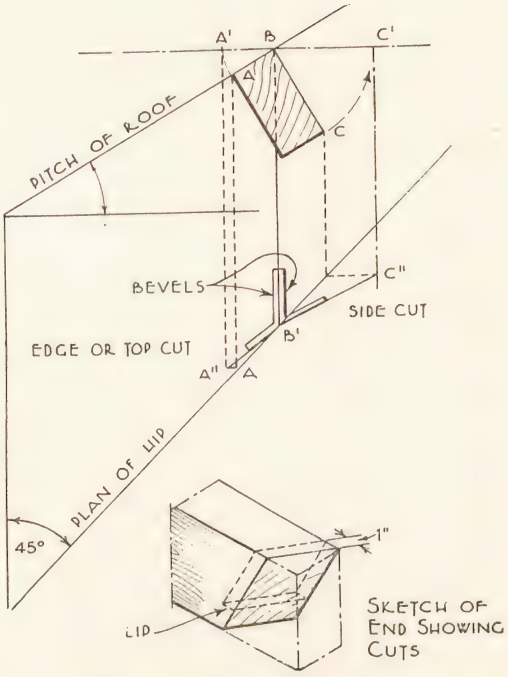


Fig. 3.—BEVELS FOR PURLINS

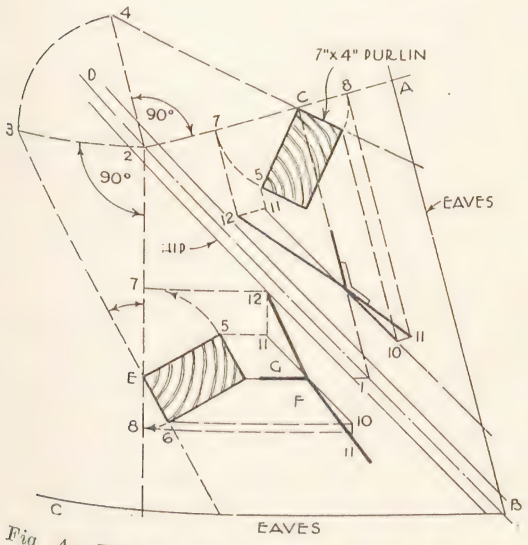


Fig. 4.—BEVELS FOR PURLINS WHERE HIP DOES NOT BISECT ANGLE, AND WALL PLATES ARE NOT AT RIGHT ANGLES TO EACH OTHER

Wind Pressure

Under the Code of Practice, 1932 (sec. 35), sloping roofs of over 20°

pitch may be designed for a combined superimposed and wind load of 15 lb. per square foot, assumed acting normal to the surface inwards on the windward side, and 10 lb. per square foot of surface similarly acting outwards on the leeward side, provided this requirement applies only in the design of the roof structure.

WEIGHTS OF ROOFING MATERIALS

Material	*Average Weight per Ft. Super in Lb.*
Slates—North Wales: Firsts	5·5
Seconds	6·5
Thirds	7·5
Cornish: Firsts	6·72
Seconds	7·84
Thirds	11·20
Westmorland: Firsts	8·4
Seconds	10·1
Thirds	12·32
Tiles—Machine-made	11·25
Hand-made	12·25
Pantiles	11·25
Asbestos tiles	3·0
Asbestos corrugated sheets	3·1
Steel corrugated sheets—18 B.W.G.	2·75
20 B.W.G.	2·25
Roof boarding—1 in.	2·5
$\frac{7}{8}$ in.	2·25
$\frac{3}{4}$ in.	1·87
Tiling battens (4-in. gauge)—2 in. by 1 in.	1·5
2 in. by $\frac{3}{4}$ in., or $1\frac{1}{2}$ in. by 1 in.	1·125
1 in. by 1 in.	0·75
Felt	0·5
	Average Weight per Sq. Ft. in Lb.
2-in. by 3-in. common rafters at 15-in. centres, 6-ft. span	1·2
2-in. by 4-in. ,, ,, ,, ,, ,, 7-ft. 6-in. span	1·6
2-in. by $4\frac{1}{2}$-in. ,, ,, ,, ,, ,, 9-ft. span	1·8
2-in. by 5-in. ,, ,, ,, ,, ,, 10-ft. ,,	2·0
2-in. by 6-in. ,, ,, ,, ,, ,, 12-ft. ,,	2·4

PURLINS FOR ALL ROOFS

Clear Span	*Distance Apart Not Exceeding*					
	6 *ft.*		7 *ft.* 6 *in.*		9 *ft.*	
	in. *in.*	*lb./sq. ft.*	*in.* *in.*	*lb./sq. ft.*	*in.* *in.*	*lb./sq. ft.*
6	3 × 5	·62	3 × $5\frac{1}{2}$	·55	3 × 6	·50
8	3 × 6	·75	3 × 7	·70	4 × 7	·70
10	4 × 7	1·2	4 × 8	1·1	5 × 8	1·1
12	4 × 9	1·5	$4\frac{1}{2}$ × 9	1·35	5 × 9	1·25
14	5 × 9	1·6	$4\frac{1}{2}$ × 10	1·50	$4\frac{1}{2}$ × 11	1·37

Snow

May be taken at 3 lb. per sq. ft.

Truss

The weight of the truss is given by Fowler's formula : ·04 span + ·4 for light roofs, and ·06 span + ·6 for heavy roofs ; or by Ricker's formula : $W = \frac{\text{span}}{25} + \frac{\text{span}^2}{6{,}000}$.

Working Stresses for Rafters

Although a list of sizes is given on page 480, everyone interested in building work should be able to calculate the most economical spacing of the rafters, and also the safe load on the beams.

In calculating the safe load on timber beams, rafters, or joists, various methods are used. The following assumes good-quality timber.

Modulus of Rupture

One method is based on the results of numerous tests on small pieces of timbers 1 in. by 1 in. in section, supported at both ends, over a span of 12 in., and loaded in the middle, the breaking weight being used as a constant. When the test piece is loaded in this way it is said to be under transverse stress, the fibres at the top being in compression and those at the bottom being in tension, while the intensity of each stress diminishes towards the centre of the beam, or the centre of gravity of the section, at which point they both vanish. Where this occurs it is called the *neutral layer* on the elevation of the beam, and the *neutral axis* in the cross-section. In beams of symmetrical section it is found at the geometrical centre of the section. The unit of transverse stress is called the *modulus of rupture*. It is sometimes supposed to be the same as the maximum fibre stress, but it is found to be greater than this.

The strength varies as $\frac{bd^2}{\text{L}}$, where b = breadth in inches, d = depth in inches, and L = span in feet. This formula does not make provision for any variation in the class of material used. This provision is expressed by the constant c, or unit load to break unit beam. It varies with the variety of wood used. For spruce or fir it is found to be 3·5 cwt., for red deal 4 cwt., for oak 4·5 cwt., and for pitch pine 5 cwt.

In the ordinary way the beam is required to carry a load safely, and to do this it is necessary to reduce the load to a fraction of the breaking weight, say $\frac{1}{5}$ or $\frac{1}{6}$, and the factor of safety F is then said to be 5 or 6, as the case may be.

The formula now becomes $\frac{cbd^2}{\text{FL}}$.

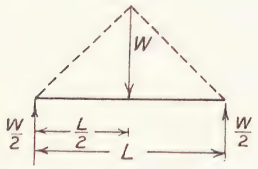


Fig. 5.—BENDING-MOMENT DIAGRAM FOR CONCENTRATED LOAD

Example.—Required the safe concentrated load in cwt. on a beam of red deal 5 in. deep, 2 in. wide, and 10-ft. span. F = 5.

$$W = \frac{cbd^2}{FL} = \frac{4 \times 2 \times 5^2}{5 \times 10} = 4 \text{ cwt.}$$

Resistance Moment

As a means of comparison we will now ascertain the load based on the moment of resistance of the beam. This is given by the following equations :—

$$BM = MR = Zf, \text{ in which—}$$

BM = bending moment.
MR = moment of resistance.
Z = section modulus of the beam.
f = permissible fibre stress in the material, usually referred to as the extreme fibre stress.

The bending produced by the load on a simply supported beam tends to shorten or compress the upper fibres, and to lengthen or put in tension the lower fibres. In the case of a simply supported beam, with a load at the centre, the maximum bending moment is $\frac{WL}{4}$, and is obtained by multiplying the reaction $\frac{W}{2}$ by the leverage $\frac{L}{2}$ (see Fig. 5). The modulus of section, $Z = \frac{bd^2}{6}$, is obtained as follows : on the section shown in Fig. 6 draw two diagonals, forming triangles, the two middle triangles showing the quantity and distribution of stress. Rectangular sections are assumed as if they were two triangles joined together at their apexes, and in consequence equally stressed in every fibre. The area ACE will be the equivalent area for compression, and EBD the equivalent area for tension. The area of each hypothetical triangle would be $\frac{b}{2} \times \frac{d}{2} = \frac{bd}{4}$.

Given that the centre of gravity of every triangle is at one-third the height from the base, and the height of the triangle is $\frac{d}{2}$, the leverage will be $\frac{d}{2} \times \frac{2}{3} = \frac{d}{3}$, and for the two triangles $\frac{2}{3}d$. The section modulus Z for any rectangular section will be the area of one triangle multiplied by the lever arm, $= \frac{bd}{4} \times \frac{2}{3}d = \frac{bd^2}{6}$.

For the specimen under consideration, the value of $Z = \frac{1 \times 1^2}{6} =$ 0·166in.^{3}. Since the specimen broke at 4 cwt., and the factor of safety

is 5, the safe load will be 0·8 cwt., which gives a bending moment of—

$$\text{BM} = \frac{\text{WL}}{4} = \frac{0{\cdot}8 \times 112 \times 12}{4} = 268{\cdot}8 \text{ lb. in.},$$

$$\text{therefore } f = \frac{\text{BM}}{\text{Z}} = \frac{268{\cdot}8}{0{\cdot}166} = 1{,}619 \text{ lb.}$$

Now to complete the problem :—

$$\text{If } \frac{\text{WL}}{4} = \text{Z}f, \text{ then } \text{W} = \frac{4\text{Z}f}{\text{L}}.$$

$$\text{W} = 4\,\frac{bd^2 \times f}{6 \times \text{L} \times 12} = \frac{4 \times 2 \times 5^2 \times 1619}{6 \times 10 \times 12}$$

$= 448$ lb. or 4 cwt.

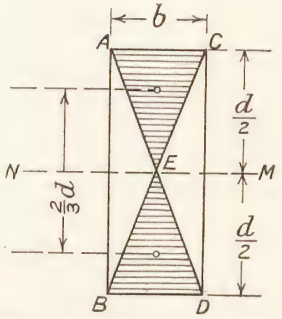


Fig. 6.—DIAGRAM SHOWING RESISTANCE AREA

The value of f_0 obtained by experiment is called the *modulus of rupture*, and will be found to be 18 times the weight that will break the beam across. This will be seen by substituting the values of l, b, and d for the experimental beam in the equation.

$$f_0 = \frac{\text{WL}}{4} \times \frac{6}{bd^2} = \frac{\text{W} \times 12 \times 6}{4 \times 1 \times 1^2} = 18\text{W}.$$

The value of f obtained by the experiments above referred to is in most cases too high, because the specimens selected for tests are usually small pieces.

WORKING UNIT STRESSES FOR STRUCTURAL TIMBER IN POUNDS PER SQUARE INCH

Timber	*Extreme Fibre Stress*		*Modulus of Elasticity, Average*	*Shearing Stress*	
	Average Ultimate	*Safe Stress*		*Parallel to Grain*	*Bending*
Spruce	5,000	1,000	1,300,000	100	80
Redwood	5,600	1,100	1,200,000	150	100
Douglas fir	6,100	1,200	1,510,000	180	120
Pitch pine	6,500	1,400	1,600,000	180	120
Oak	6,500	1,400	1,200,000	200	120

Design of Boarding

In making up the load carried by the various members it will be found convenient to determine the resultant load carried by one square foot. From the Table previously given, slates (thirds) weigh 7·5 lb., battens (2 in. by $\frac{3}{4}$ in.) 1·125 lb., felt 0·5 lb., and boarding 2·5 lb., per square foot respectively. The dead load will then be 11·625 lb. per square foot of roof area. To this must be added half the proposed snow load (1·5 lb.), as a maximum wind pressure (15 lb.) and a snow load are not likely to

occur at the same time. Adding these amounts together the total load including the boarding will be 28·125 lb. per square foot.

Assuming that the rafters are spaced at 15-in. centres, the moment due to the load will be $\frac{1}{8}\ Wl^2 = \frac{28{\cdot}2 \times 1{\cdot}25^2 \times 12}{8} = 66$ in. lb. approximately.

This moment is resisted by a $\frac{7}{8}$-in. by 12-in. section of boarding, for which the resulting fibre stress will be $f = \frac{\text{BM} \times 6}{bd^2} = \frac{66 \times 6}{12 \times \frac{7}{8}^2} = 43$ lb. per square inch, which is very low, and indicates that for ordinary conditions the design for boarding need not be carried out.

Design of Rafters

For the rafters assume a 2-in. by 4-in. section, and 8-ft. span. At 2 lb. per foot run the dead weight per foot of rafter is $\frac{2 \times 8}{8 \times 1{\cdot}25} = 1{\cdot}6$ lb. Adding the weight of the rafter the total load to be carried by the rafter is a uniform load of 29·8 lb. per square foot.

The moment is $\frac{Wl^2}{8} = \frac{29{\cdot}8 \times 8 \times 1{\cdot}25 \times 8 \times 12}{8} = 3{,}576$ lb. in.

The section modulus of a 2-in. by 4-in. rectangle is $\frac{1}{6}bd^2 = \frac{1}{6} \times 2 \times 4^2 = 5{\cdot}33$ in.^{3}, and the fibre stress is $f = \frac{\text{BM} \times 6}{bd^2} = \frac{3576 \times 6}{2 \times 4^2} = 670{\cdot}5$ lb. per square inch. As the allowable fibre stress is 1,000 lb. per square inch, the assumed section is sufficient.

The maximum span for the rafters to carry the above loading of boarding, battens, and slates, and also a wind pressure of 15 lb. per square foot, making a total of 29·8 lb. per square foot, may be worked out as follows :—

Assuming a safe fibre stress of 1,000 lb. per square inch, and a nominal breadth b of the rafters as 2 in., spaced at 15-in. centres :—

Then, $\text{BM} = \frac{\text{WL}}{8}$, $\text{W} = \text{L} \times \frac{15}{12} \times 29{\cdot}8$ lb. $= 37{\cdot}25\text{L}$.

Therefore $\text{BM} = \frac{37{\cdot}25\text{L} \times \text{L} \times 12}{8} = 55{\cdot}87\text{L}^2$.

The moment of resistance $\text{MR} = \frac{bd^2}{6} \times f = \frac{2 \times d^2 \times 1000}{6} = \frac{1000d^2}{3}$.

Equating the bending moment to the moment of resistance :—

$$\text{BM} = \text{MR}$$

$$55{\cdot}87\text{L}^2 = \frac{1{,}000d^2}{3}$$

$$\frac{55{\cdot}87\text{L}^2 \times 3}{1000} = d$$

$$\therefore d = \sqrt{{\cdot}1676\text{L}} = {\cdot}409\text{L}.$$

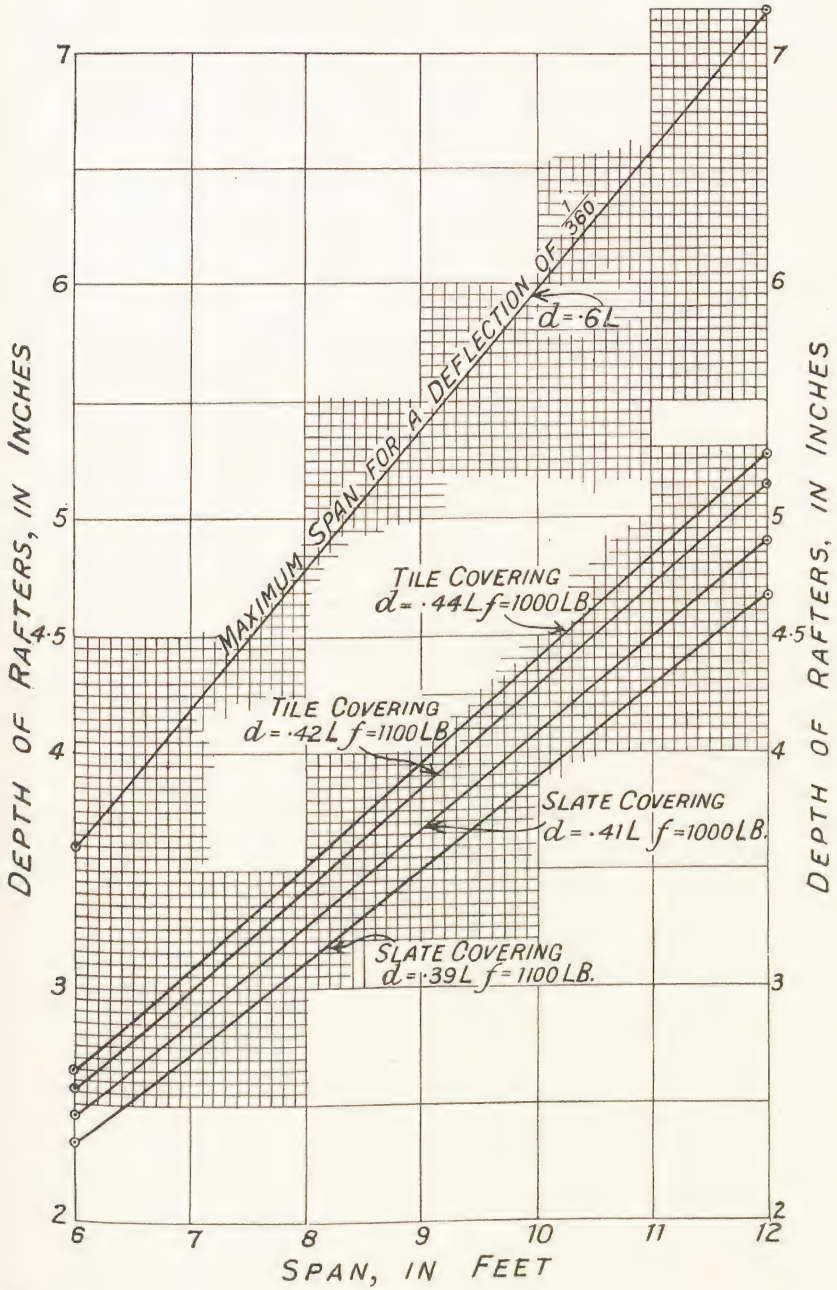


Fig. 7.—GRAPH TO DETERMINE DEPTH OF 2-IN. RAFTERS, AT 15-IN. CENTRES, FOR SLATES AND TILES

The depth of the rafters will therefore be, say, ·41 of the span in feet. For $f = 1{,}100$ lb., $d = \cdot 39\text{L}$.

Where handmade tiles are used in lieu of slates, the loading will be increased by the difference between the weight of the slates and the weight of the tiles, i.e. the difference between 7·5 and 12·3 lb., or 4·8 lb., making a total load of 34·6 lb. Working this out in the same way as that used for slates, the depth will be found to be ·441L for $f = 1{,}000$ lb., and ·42L for $f = 1{,}100$ lb. These rules are shown plotted in the graph, Fig. 7.

When the rafters are required to carry a plaster ceiling, the deflection is usually limited to $\frac{1}{360}$ of the span to prevent cracks in the plaster. This condition will necessitate the rafters being designed for stiffness instead of strength. Taking the safe fibre stress at 1,000 lb. per square inch, and E the modulus of elasticity at 1,510,000 :—

The deflection of a rectangular beam under a uniform load is given by the formula $\Delta = \frac{5}{384}\frac{\text{WL}^3}{\text{EI}}$, or for a maximum deflection of $\frac{1}{360}$:—

$$\frac{5}{384}\frac{\text{WL}^3}{\text{EI}} = \frac{\text{L}}{360}.$$

Dividing by L and substituting the given value of E, we get :—

$$\frac{5\text{WL}^2}{384 \times 1510000\,\text{I}} = \frac{1}{360}$$

$$\therefore \quad \frac{\text{WL}^2}{322133} = \text{I} \quad . \quad . \quad (1)$$

Again, for a beam of any symmetrical section, we know that :—

$$\frac{\text{Moment of inertia of section}}{\text{Modulus of section}} = \frac{\text{depth}}{2}.$$

Now Z = moment of resistance ÷ stress $= \frac{\text{MR}}{f}$. Hence, substituting for Z :—

$$\text{I} = \frac{\text{MR}}{f} \times \frac{\text{D}}{2}.$$

But for a beam with a distributed load, $\text{BM} = \frac{\text{WL}}{8}$,

$$\therefore \quad \text{I} = \frac{\text{WL}}{8f} \times \frac{\text{D}}{2} = \frac{\text{WLD}}{16f} \quad . \quad . \quad . \quad . \quad (2)$$

Combining results (1) and (2) we have :—

$$\frac{\text{WL}^2}{322133} = \frac{\text{WLD}}{16f}$$

$$\therefore \quad \frac{\text{L}}{\text{D}} = \frac{322133}{16 \times 1000} = \frac{20}{1}.$$

Hence the depth of a uniform beam must not be less than $\frac{1}{20}$ of the span in feet, or $\frac{1 \times 12}{20} = \cdot 6$ of the span in inches if the deflection has not to exceed $\frac{1}{360}$ of the span (see graph, Fig. 7).

Maximum Span

The maximum span for rafters of a nominal breadth of 2 in. and a spacing of 15 in., to carry slates or tiles on boarding, etc., is given in the Table below.

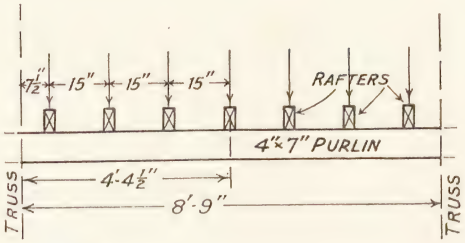


Fig. 8.—LOADS ON PURLIN

Design of Purlins

The purlin section is set at right angles to the rafter. It is then subjected to a normal load due to the rafters. The loads coming on the purlins from the rafters may be considered as being distributed, which gives a maximum moment slightly less than when they are considered as concentrated loads on each rafter (see Fig. 8). The span will be taken as 8 ft. 9 in., and the distance apart 8 ft., giving an area of 70 sq. ft. The weight of the purlin over this area is ·86 lb. per square foot, therefore the weight to be designed for is 29·8 + ·86 = 30·66 lb. per square foot over an area of 70 ft., = 2,146·2 lb.

Common Rafters Nominal Dimensions	*Maximum Span*	
	Slates	*Tiles*
in. in.	*ft.*	*ft.*
2 × 3	7·3	6·8
2 × 4	9·75	9·1
2 × 4½	11·0	10·2
2 × 5	12·1	11·3
2 × 6	14·6	13·4

Using a 4-in. by 7-in. section as given in the Table on page 480, the safe fibre stress will be :—

$$f = \frac{2146 \times 8{\cdot}75 \times 12 \times 6}{8 \times 4 \times 7 \times 7} = 860 \text{ lb. per square inch.}$$

Taking the loads to act at the centre of the rafters, the maximum moment is :—

$$M = \left[\left(\frac{2146}{2} \times \frac{8{\cdot}75}{2}\right) - \frac{2146}{7}(1{\cdot}25 + 2{\cdot}5 + 3{\cdot}75)\right]12$$

$$= [(4694{\cdot}375) - (2299{\cdot}125)]12 = 28{,}743 \text{ in. lb.}$$

$$\text{Modulus section of purlin} = \frac{4 \times 7 \times 7}{6} = 32{\cdot}66.$$

$$\text{Maximum stress in the timber} = \frac{28743}{32{\cdot}66} = 880 \text{ lb.}$$

Stress Diagrams for Roof Trusses

The method by which the stress in each member of a roof truss is found graphically is explained in the following example of a king-post roof truss. Suppose the span to be 24 ft., trusses placed at 10-ft. centres, the roof slope 30°, and the covering, slates on battens and boarding (see Fig. 9).

Assume weight or dead load as previously worked out is 15·66 lb. per square foot, but to this must be added the weight of the truss. Using Jacoby's formula for wooden roofs, W = ·075 span + ·5 = 24 × ·075 + ·5 = 2·3 lb. per square foot, making a total load of 17·96 lb. per square foot. The wind pressure of 15 lb. per square foot of surface is assumed to be acting normal to the surface inwards on windward side, and 10 lb. per square foot of surface similarly acting outwards on the leeward side, and a ceiling load of 10 lb. per square foot.

The slope length is $\frac{\text{half-span}}{\cos . 30^\circ} = \frac{12}{0{\cdot}866} = 13{\cdot}85$ ft.

Then *dead load* = 13·85 × 10 × 17·96 = 2,487·4 lb.

Load on central points $= \frac{2487{\cdot}4}{2 \times 112} = 11{\cdot}1$ cwt.

Load on end points $= \frac{2487{\cdot}4}{4 \times 112} = 5{\cdot}5$ cwt.

Wind load = 13·85 × 10 × 15 = 2,077·5 lb.

Load on central point $= \frac{2077{\cdot}5}{2 \times 112} = 9{\cdot}27$ cwt.

Load on end points $= \frac{2077{\cdot}5}{4 \times 112} = 4{\cdot}63$ cwt.

Suction = 13·85 × 10 × 10 = 1,385 lb.

Load on central point $= \frac{1385}{2 \times 112} = 6{\cdot}2$ cwt.

Load on end points $= \frac{1385}{4 \times 112} = 3{\cdot}1$ cwt.

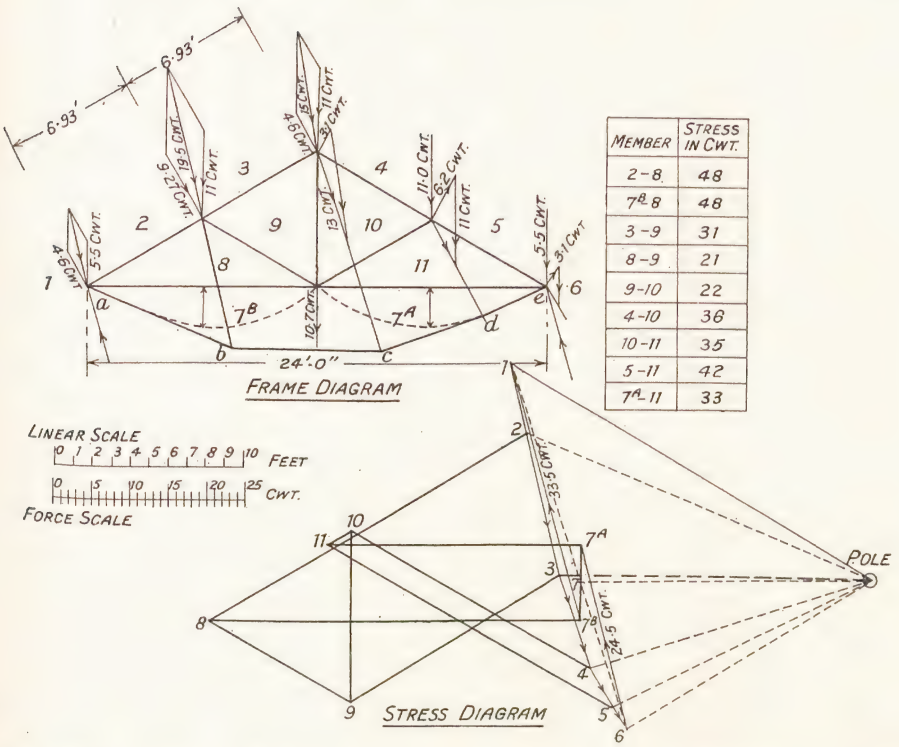
Ceiling load = 24 × 10 × 10 = 2,400 lb.

Load on central point $= \frac{2400}{2 \times 112} = 10{\cdot}7$ cwt.

Load on end points $= \frac{2400}{4 \times 112} = 5{\cdot}35$ cwt.

The latter are taken directly by the walls, and need not be considered.

To a scale of $\frac{1}{4}$ in. to a foot, draw the frame diagram, and indicate on the figure the forces combining the wind and dead loads. The dead load and wind pressure acting on the same point can be represented in magnitude and direction by two adjacent sides of a parallelogram, and their resultant is represented by the diagonal of the parallelogram



MEMBER	STRESS IN CWT.
2–8	48
7^B–8	48
3–9	31
8–9	21
9–10	22
4–10	36
10–11	35
5–11	42
7^A–11	33

Fig. 9.—FRAME DIAGRAM OF KING-POST WITH STRUCTURAL LOAD, WIND PRESSURE, AND SUCTION

drawn from the point of application. The spaces must next be numbered or lettered between the forces acting on the frame.

Draw the load line 1, 2, 3, 4, 5, 6, and take any pole O. Draw the radial lines O1, O2, etc., and across the corresponding spaces 2, 3, 4, etc., on the frame diagram, draw parallel lines forming the funicular polygon *abcde*. Draw the closing line *ae*, and from the pole O draw a parallel line cutting the load at point 7. If there had been no ceiling load the lines drawn from this intersection to the points 1 and 6 would have given the magnitude and direction of the reactions 1–7 and 6–7. The addition of the ceiling load will obviously increase the reactions, and also cause the reactions to assume a more vertical direction. From the point 7 on the temporary reaction line, set up on each side half the magnitude of the central ceiling load, giving points 7^A and 7^B. Join point 1 to 7^B, and 6 to 7^A. This gives the magnitude and direction of the two reactions (see Fig. 9). Next draw the stress lines parallel to the members of the truss: 2–8, 7–8; 3–9, 8–9; 9–10, 4–10; 10–11, 7–11; and 5–11. The forces in the frame can now be scaled off, and

the magnitude of the stress in each member of the truss tabulated as below :—

Member	2–8	7^B–8	3–9	8–9	9–10	4–10	10–11	7^A–11	5–11
Magnitude of stress, in cwt.	48	48	31	21	22	36	3·5	42	38

The usual formula for roof members in compression is the Rankine-Gordon formula, and is :—

$$P = \frac{fA}{1 + \frac{1}{ac}\frac{l^2}{r^2}}$$

Where P = ultimate load in pounds.

$f = \frac{2}{3}$ of the ultimate compressive strength of the material in pounds per square inch, say 4,000 lb. for fir.

a = constant = 1 for column with round ends ; 2 for column with one end rounded.

c = constant = 750 for timber.

l = length of column in inches.

r = least radius of gyration of cross-section = $\sqrt{\frac{I}{A}}$ or $r^2 = \frac{I}{A}$

where I = moment of inertia = $\frac{bd^3}{12}$ for a rectangular section, and A = area of cross-section.

For the principal rafter the maximum stress is 5,376 lb. and the unsupported length 6·94 ft.

Assume a scantling of 5 in. by 4 in., then :—

$$P = \frac{4000 \times 20}{1 + \frac{1}{2 \times 750}\frac{(6{\cdot}94 \times 12)^2}{1{\cdot}33}} = 17{,}937 \text{ lb.}$$

Adopting a factor of safety of 4, the safe load will be $\frac{17937}{4} = 4{,}480$ lb. or 40 cwt. The section 5 in. by 4 in. is too small. Try a 5-in. by 5-in. section and work out as before.

For the struts with a maximum compression of 21 cwt., and an unsupported length of 6·94 ft., try a section 5 in. by $2\frac{1}{2}$ in., then :—

$$P = \frac{fA}{1 + \frac{1}{ac}\frac{l^2}{r^2}} = \frac{4000 \times 12{\cdot}5}{1 + \frac{1}{2 \times 750}\frac{(6{\cdot}94 \times 12)^2}{1{\cdot}33}}$$

$$P = 11{,}185 \text{ lb.}$$

and $\frac{11185}{4} = 2{,}796$ lb. or 24 cwt. safe load.

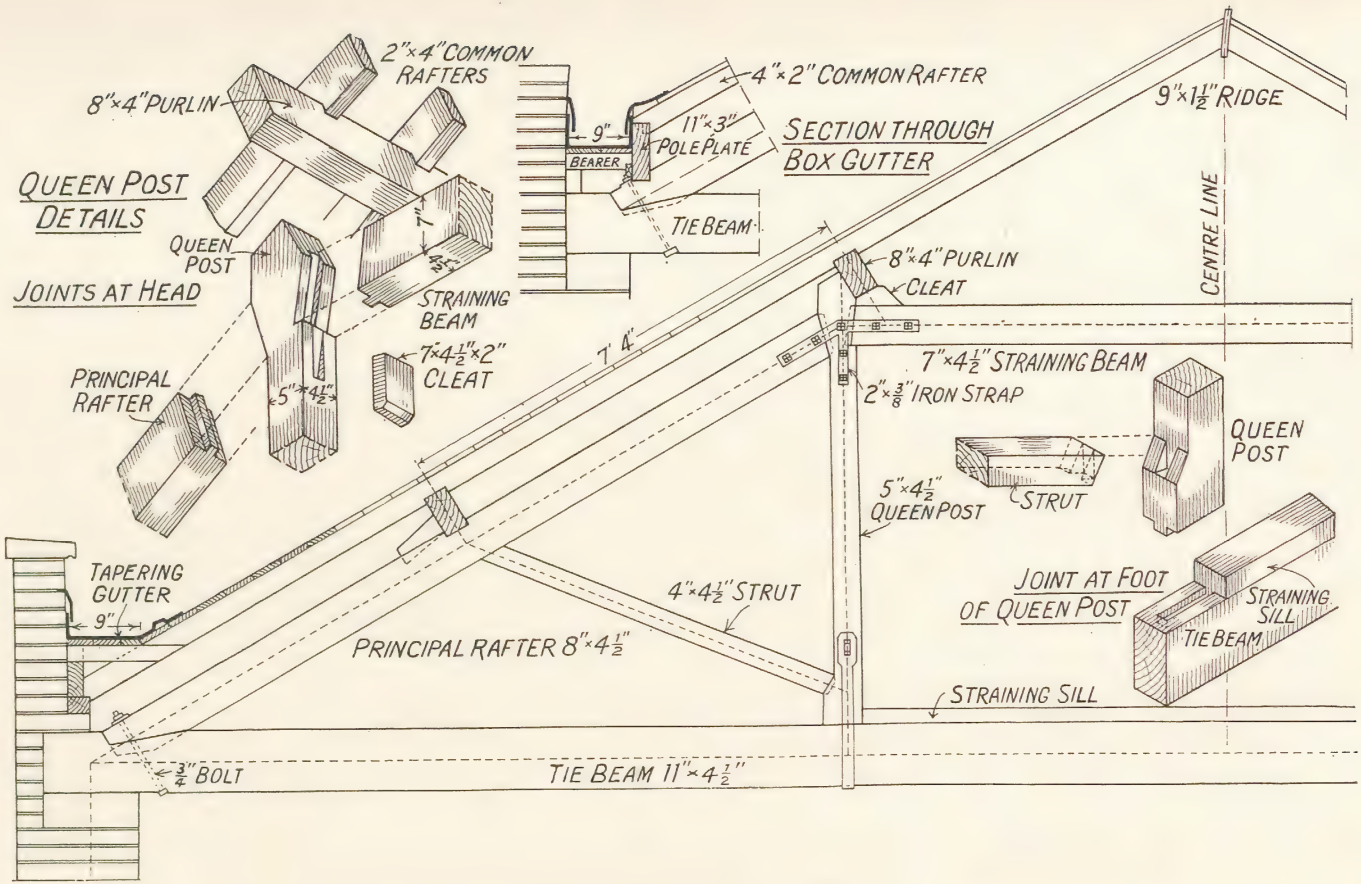


Fig. 10.—QUEEN-POST ROOF TRUSS

The king-post has a tensional stress of 22 cwt., and allowing 2·5 cwt. per square inch on the net area in tension, the king-post will require an area of $\frac{24}{2 \cdot 5} = 9 \cdot 6$ sq. in., say, 4 in. by 3 in.

The tie-beam has a maximum tension of 48 cwt., and a maximum bending moment $\frac{WL}{8} = \frac{10 \cdot 7 \times 12}{8} = 16$ cwt. ft. or 192 cwt. in.

Try a 10-in. by 5-in. section, then :—

$$-\frac{W}{A} \pm \frac{M}{Z} = -\frac{48}{50} \pm \frac{192}{\frac{1}{6}(5 \times 10^2)}$$

$$= - \cdot 96 \pm 2 \cdot 3 = 3 \cdot 26 \text{ cwt. per square inch in tension,}$$

and 1·34 cwt. per square inch in compression, which is satisfactory.

Queen-post Trusses

These are used for spans of from 30 ft. to 45 ft., the tie-beam and rafters being supported at two intermediate points in their length, instead of only at one. The two queen-posts are connected at their tops by a horizontal member called a *straining beam*, and the junction of these affords a support at one point for the rafters (see Fig. 10). The principal rafter ends at this point, and is not carried to the ridge as in the king-post roof truss. A support for the middle of the principal rafter is obtained by the strut which springs from the base of the queen-post. The purlin over this point occurs at about a third of the distance along the common rafter, the second purlin at the top of the queen-post being another third, which provides the necessary support to the common rafters.

The thrusts from the struts are resisted by a tenon on the foot of each post, and a member called a *straining cill*. Many of the details of this truss are the same as those of the king-post truss previously described and illustrated (see Fig. 10).

Queen-post roof trusses are not much in use at the present time, owing to the increased use of steel for large-span roofs, but they can be used with advantage where a lantern light has to be fixed in the centre. The Table on page 493 gives the scantlings for queen-post roof trusses.

Mansard or Curb Roof

The Mansard or curb roof is essentially one with two pitches, and is usually employed as a means of economising space. In roofs of ordinary pitch a great amount of the space is lost, due to the sharp pitch of the sides, but in the Mansard roof this is overcome by making the sides of the lower pitch nearly vertical. The upper slope is then made relatively flat to avoid an acute ridge. Fig. 11 is an isometric view of this roof, and Fig. 12 shows the details of the joints.

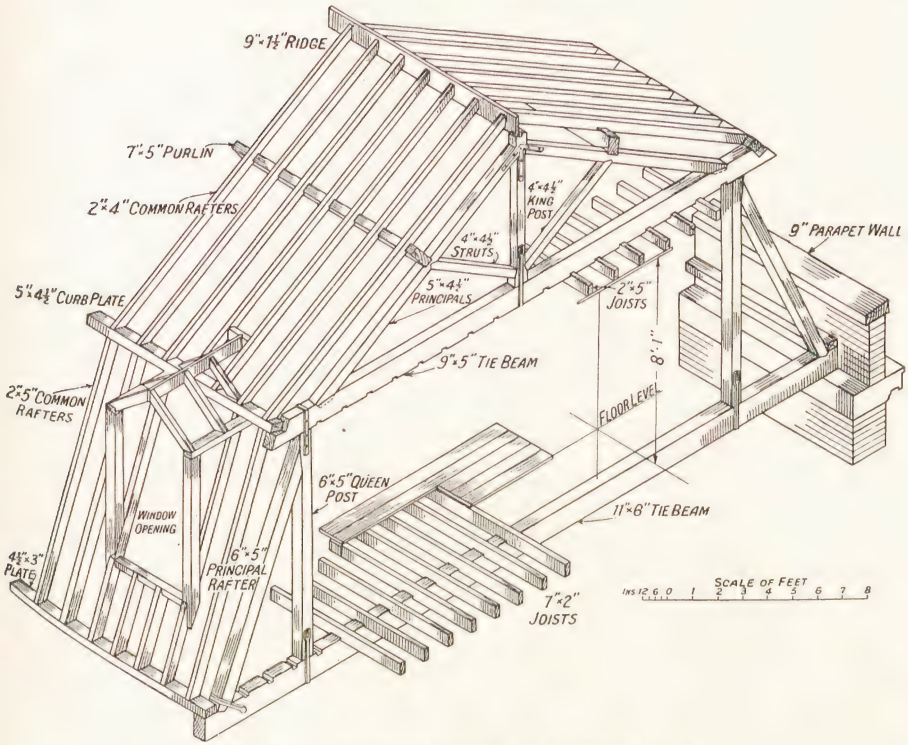


Fig. 11.—ISOMETRIC SKETCH OF MANSARD ROOF

DIMENSIONS OF TIMBERS FOR QUEEN-POST TRUSSES
10 FT. APART, PITCH 30°, SLATED

Span	*Thickness of Truss Members*	*Breadth on Elevation*					
		Tie-beam	*Principal Rafter*	*Queen-post*	*Struts*	*Straining Beam*	*Straining Cill*
ft.	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
32	4	9	4½	4	2	6	3
34	4½	10	5	4	2	6½	3½
36	5	10½	5½	4½	2	7	4
38	5½	11	5½	4½	2¼	7½	4
40	5½	11½	6	5	2½	8	4½
42	6	12	6	5	2½	8	5
44	6	12	6½	5½	2½	8½	5

Composite Roof Trusses

Roofs formed or built up of a combination of timber and steel members are known as composite trusses, the compression members

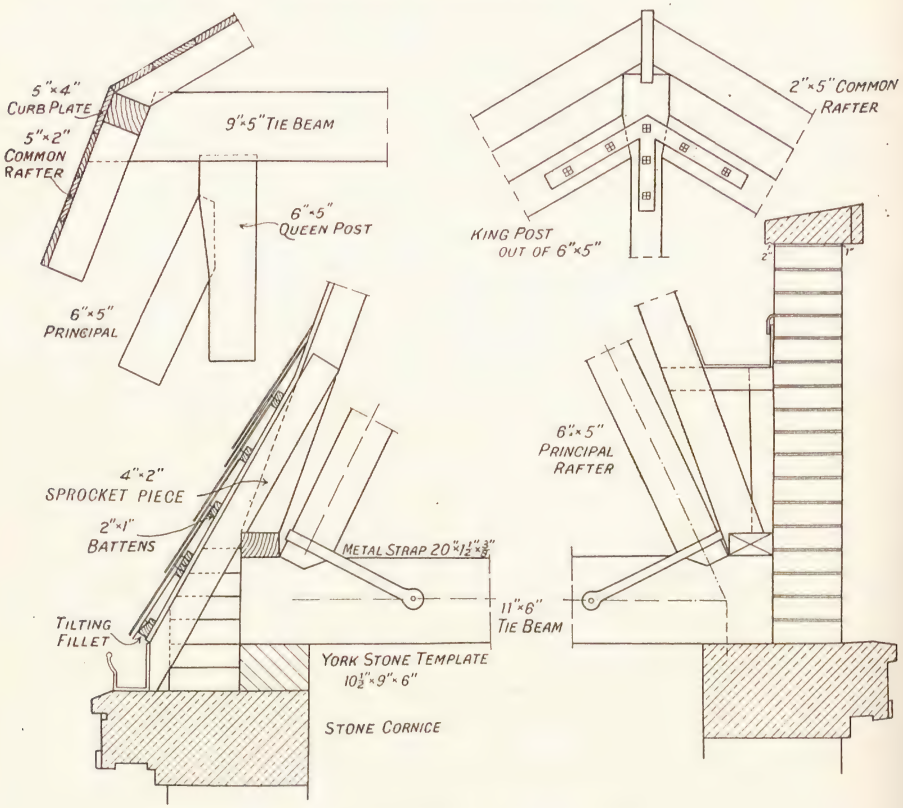


Fig. 12.—MANSARD ROOF DETAILS

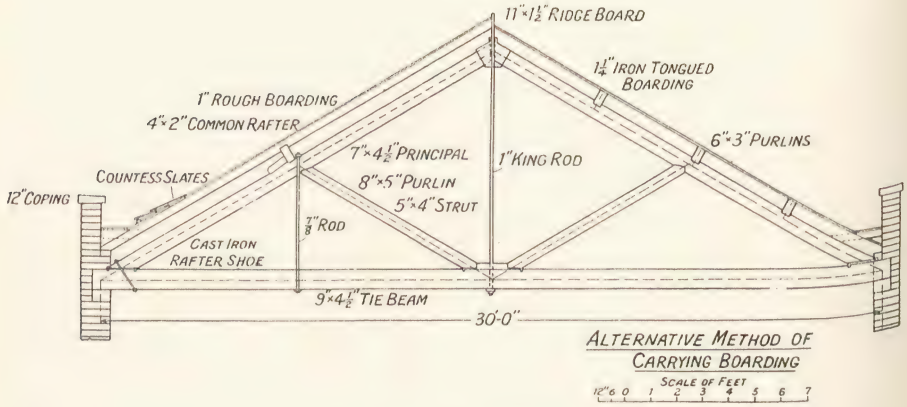
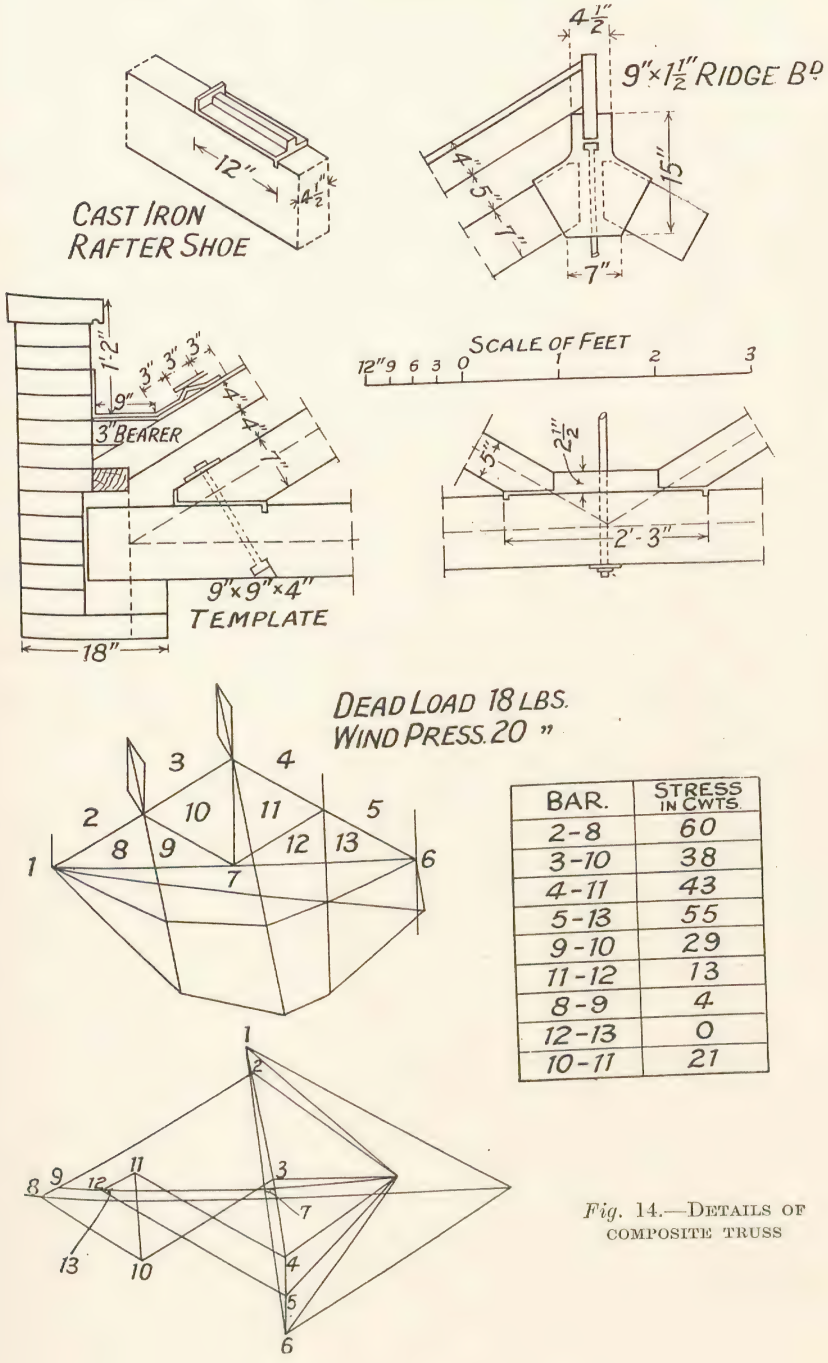


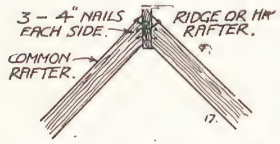
Fig. 13.—COMPOSITE TRUSS
Showing alternative methods of carrying boarding.



BAR.	STRESS IN CWTS.
2-8	60
3-10	38
4-11	43
5-13	55
9-10	29
11-12	13
8-9	4
12-13	0
10-11	21

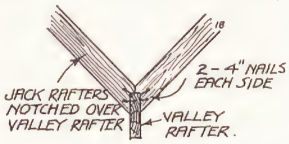
Fig. 14.—DETAILS OF COMPOSITE TRUSS

being of timber and the tension members of steel, which from its great tensile strength is more suitable, but these roofs are not very frequently used (see Fig. 13). Alternative methods of construction are illustrated.



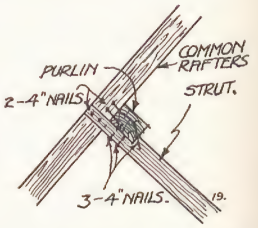
JOINT BETWEEN RAFTERS AND RIDGE

Joint between jack rafters and hip rafter similar.

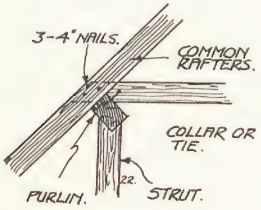


JOINT BETWEEN RAFTERS AND VALLEY RAFTER

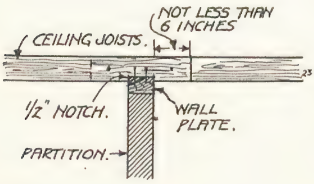
Rafters notched over valley rafter, with as much timber in rafters over top of valley as possible. Nail as shown.



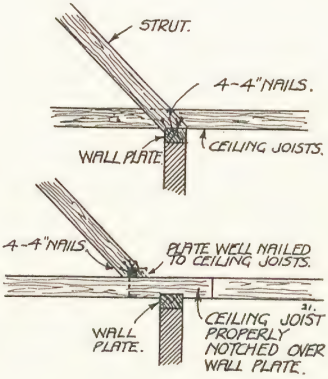
JOINT BETWEEN RAFTERS, PURLIN, AND STRUT WHERE LATTER IS AT ABOUT RIGHT ANGLES TO RAFTERS



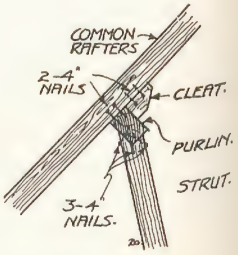
JOINT BETWEEN COLLAR AND PURLIN



JOINT BETWEEN CEILING JOISTS AND PLATE WHERE JOISTS CANNOT BE CONTINUOUS OVER PLATE



JOINTS BETWEEN BOTTOM OF STRUTS AND PLATES



JOINT BETWEEN RAFTERS, PURLIN, AND STRUT WHERE STRUT IS NOT SET AT ABOUT RIGHT ANGLES TO RAFTERS

Fig. 15.—JOINTS BETWEEN SOME ROOF MEMBERS

CORNICES AND STRING COURSES

CORNICES may be employed both externally and internally as ornamental features in a building, but their practical uses differ according to their positions.

External Cornices

External cornices, forming the upper terminations of walls or architectural embellishments, act also as a protection to the building by throwing rain-water clear of the wall face, or conveying it away to discharge into a gutter.

The practical use of external cornices is thus that of a coping, and the most important feature in their design is the drip, or undercut projection, which by checking the capillary action of the water prevents it from running back over the various mouldings below, and so streaming down the face of the wall.

The second important point to be remembered is the weathering of the flat, upper surface of the stone, either forward to throw off the water rapidly, or backward to a specially constructed gutter.

Internal Cornices

Internal cornices are usually placed at the junction of walls and ceilings to soften the hard outline of the angle, thus performing, in the main, a purely artistic purpose. The drip is therefore not an essential, but the traditional form has become so settled that most internal cornices are built up with a strong resemblance to external ones, although a greater licence is adopted in the profiles, which may vary almost indefinitely.

Classic Cornices

The origin of the traditional cornice form may be found in the upper portion of the entablature of the classic orders employed by the Greeks and Romans. This entablature consisted of an architrave, frieze, and cornice, which formed the portion of the wall immediately above the columns. Although the proportions differed between the Doric, Ionic, and Corinthian orders, there was always a definite relationship between the height of the column and the height of the entablature. The latter was divided into four parts, the architrave equalling one of these, while the remaining three parts were divided equally between the frieze and the cornice.

The Composition of a Cornice

A properly designed cornice comprises two parts. The upper, called the corona, includes the top or gutter moulding as well as the projecting drip, and should occupy two-thirds of the total depth. The remaining one-third is called the bed mould, and consists of all those mouldings below the deep horizontal setback of the drip stone.

Dentils and Modillions

In addition to the mouldings, several features are included in a modern cornice which are really petrified memories of the time when all building was carried out in wood. One of these is a row of small blocks, cut in the lower bed mould, called dentils. These were once the projecting ends of the roof rafters, but are now nothing more than ornaments. Another is the projecting bracket called a modillion, which is placed immediately under the projecting corona, and once served to support the soffit above when made of wood. To-day, this feature, like the dentil, is purely ornamental. In small cornices these enrichments are out of place, but in large ones they add interest to the appearance, and give scale to the building on which they are placed.

Cornices without Columns

Where the design of a building includes columns or pilasters, the classic proportions of the cornices suitable to the order employed should be generally observed. But many buildings are not so ornamented, and another method must be found to obtain the proportion of the cornices suitable to the height of the wall. One way is to imagine a column the height of the wall, and to design a cornice of the correct depth for the column, but the Renaissance architects worked out largely by trial and error a series of proportions between the height of the wall and the depth of the cornice, irrespective of the proportions associated with the classic orders. It was found to be generally satisfactory to divide the height of the wall into twenty-five parts, and to make the depth of the cornice equal to two of these parts. The rule is not a hard and fast one, as the following Table of some actual proportions employed by the architects in designing some well-known cornices will show.

Strozzi	Palace,	Florence.	Cornice	$\frac{2}{29}$	of height of wall.
Gondi	,,	,,	,,	$\frac{1}{16}$	,,	,,
Farnese	,,	Rome.	,,	$\frac{1}{17}$	,,	,,

The appearance of a cornice depends very much on the position from which it may be seen, and many old buildings were built, like modern ones, in streets from which only a restricted view may be obtained. It is an excellent check on a design to have a small section of the proposed cornice made up as a wooden model, and placed in position for final corrections before the stone is actually cut. It will often be found that

certain shapes and projections which look well when drawn at eye level lose themselves completely when in position, and these optical corrections can be made on the full-size model.

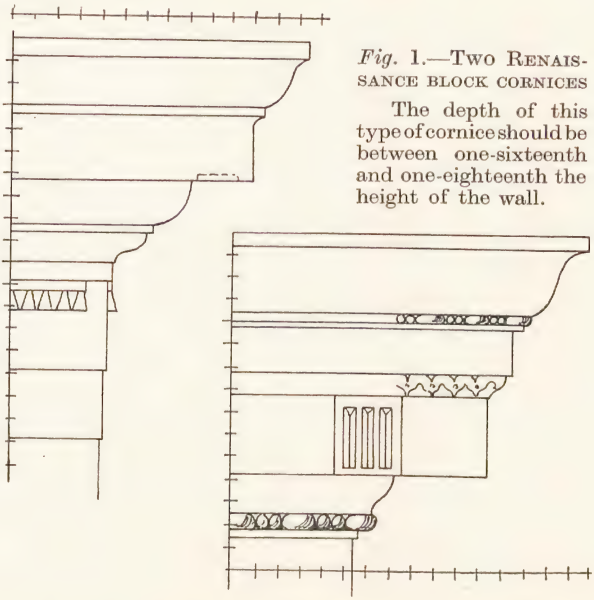


Fig. 1.—TWO RENAISSANCE BLOCK CORNICES

The depth of this type of cornice should be between one-sixteenth and one-eighteenth the height of the wall.

Block Cornices

These are a modification of the classic type, and are suitable for finishing off a wall of a building of a simple character (Fig. 1). The depth of a block cornice should be between one-sixteenth and one-eighteenth the height of the wall, and while following the general principles of a classic cornice, allows more freedom in the employment of the different mouldings. The only important feature, which must in all cases be retained, is the drip moulding for throwing off rain-water.

Parts of a Cornice

The mouldings which make up a cornice are known by definite names according to the sections of their profiles. These are the cavetto, or concave moulding; the ovolo, or convex moulding; the cyma recta, a combination of the two forms having the upper part concave; and the cyma reversa, a similar combination with the convex moulding at the top. These forms, combined with straight vertical and horizontal faces, are employed in all cornices in one way or another, and the following description shows how to set out the full-size profiles in designing them (Fig. 2).

(1) *The Cavetto.*—This is a hollow forming the quadrant of a circle whose chord is the diagonal of a square, and radius equal to one of the sides.

(2) *The Ovolo.*—This is set out in a similar manner to the cavetto, but on the reverse side of the diagonal, thus producing a convex shape.

(3) *The Cyma Recta.*—This is a double curve set out along the diagonal of a square. To draw it, first divide the diagonal into four parts, and with a radius equal to half the diagonal describe a circle.

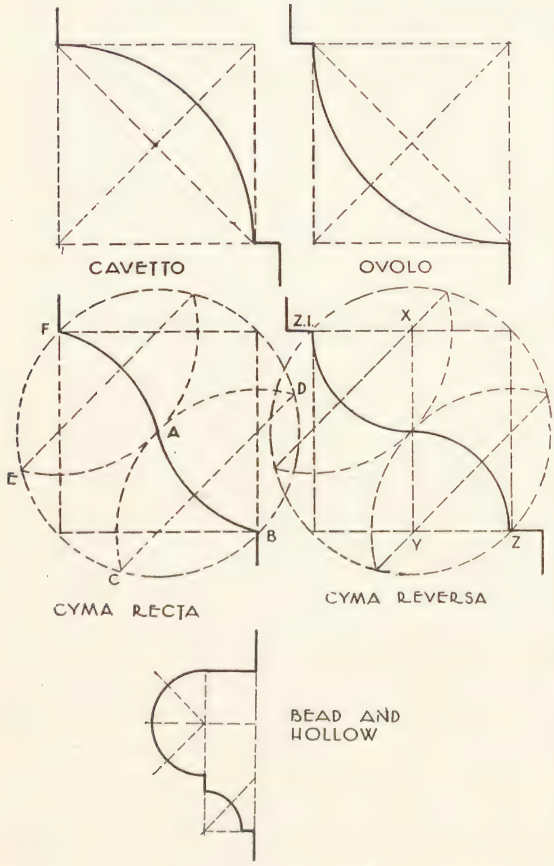


Fig. 2.—METHOD OF SETTING OUT CORNICE MOULDINGS

With centre B, and radius BA, describe a segment to cut the circumference of the first circle at C and D. With centre D, and radius DA, describe the segment AB, and this curve AB will be the profile of the lower part of the cyma recta. Repeat the process, and the curve AF struck from the centre E will be the profile of the upper part.

(4) *The Cyma Reversa.*—To set out a cyma reversa moulding, bisect the sides of the square at X and Y; with centre Y, and radius YZ, describe the quadrant, and from centre X with radius XZ1 describe another quadrant. These quadrants will give the profile of the moulding required.

If a flatter form of the cyma reversa is required, it may be set out in the same manner as the cyma recta, but with the convex portion at the top.

(5) *The Bead and Hollow.*—These mouldings may be set out with a pair of compasses, as shown in Fig. 2.

Arrangement of Mouldings

The top member of a cornice is usually formed with a cavetto or a cyma recta, which in modern wood cornices is commonly a gutter composed of one of the stock-pattern cast-iron gutters on the market. A small mould, either a bead or a hollow, divides the top moulding from the vertical face of the drip immediately below. It is under this drip that the modillions are placed in large cornices, but in small ones the top moulding of the bed is formed with a cyma reversa or ovolo, the convex face giving the appearance of support which is needed under the wide overhang of the drip stone. The bottom moulds are often formed with a cavetto or another cyma reversa, and below there is sometimes a bead and reel on a fillet.

Enrichment of Mouldings

All these mouldings have their appropriate ornament. The ovolo may be carved with the egg and tongue pattern, the cyma reversa with a leaf ornament, and the bead with the form known as bead and reel (Fig. 3). Modillions may also either be simple moulded brackets, or elaborated with scroll ornaments, often having an acanthus leaf on the under side.

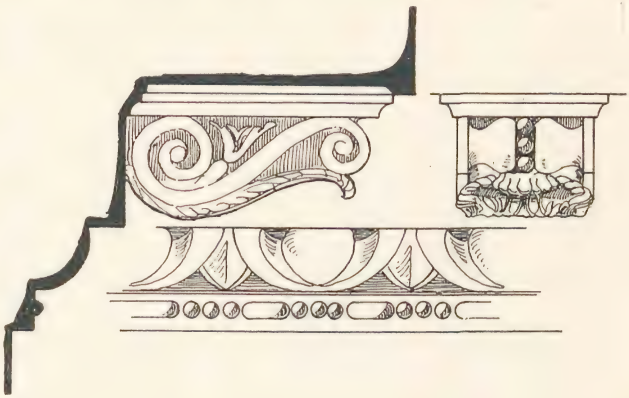


Fig. 3.—CORNICE WITH ENRICHED MODILLIONS, EGG AND TONGUE ORNAMENT, AND BEAD AND REEL

Projection of the Cornice

In many textbooks cornices are shown drawn in section, the profile usually contained within an angle of 45°. This is satisfactory if the cornice to be erected is in a long length without return angles, but as most cornices are carried round the sides as well as along the front of a building, the result is that the most conspicuous point of their projection is at the mitre, where the profile should be contained within an angle of 45°, and not along the straight face.

The full-size section given to the mason or carpenter is always a true one, and the following method is a way of ensuring that the mitre shall not exceed 45° (Fig. 4). Draw a plan of the angle of the wall, and set out the total projection of the cornice. Draw the mitre line at the angle jointing the projection with the wall face. Now set up a vertical section of the wall, and set off horizontally a line equal to the mitre line. From the extreme point draw a line at an angle of 45° to the wall, and this will give the depth of the cornice. Then take a true section through the cornice and set it off on the horizontal line on the section. Join this point with the bottom of the cornice, and the true profile must fall within this triangle to give a 45° angle at the mitre. It will be found by measuring with a protractor that this angle is in the neighbourhood of 52°. Fig. 5 shows another method of determining the profile when the angle of the building is not a right angle. The cornice section is designed on the mitre line, and projected to cut the plan vertically. Where the lines cut the plane they are continued parallel to the angle of the splay, and the true section set up on them. It will be found that in an obtuse

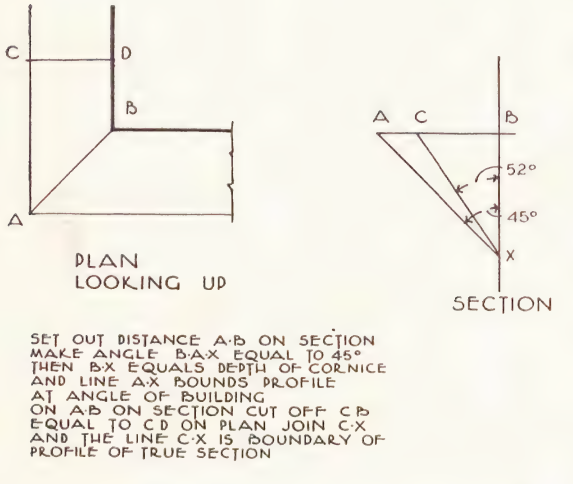


Fig. 4.—SETTING OUT PROFILE OF RIGHT-ANGLE CORNICE

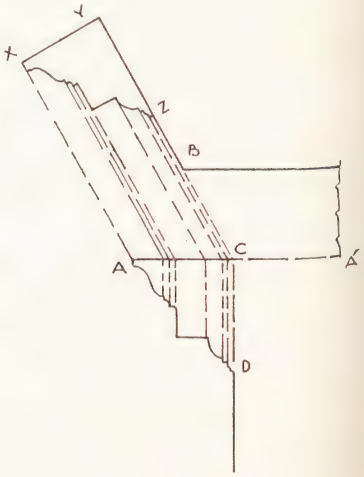


Fig. 5.—SETTING OUT PROFILE OF CORNICE AT ANGLE

On line AA′ set out AC equal to mitre line AB. Join AD at angle of 45°, and draw profile of cornice. Project mouldings on to line AC and parallel to splay of wall till they cut line XY. Set off YZ equal to CD. Join XZ, and draw true profile of cornice within it, the vertical depth of each moulding being equal to those on AD.

angle the true section will be less than 52°, and on an acute angle greater than 52°, the actual mitre being in each case 45°.

When a building has an irrègular-shaped plan there may be a number of different angles, but it should be remembered in designing a cornice that it is better to have too slight rather than too full a projection. Nothing spoils the appearance of a building more than an ugly, sprawling cornice.

String Courses

It has been said that a string course is the architect's method of drawing lines on his building, and the purpose of a string is frequently purely æsthetic, providing, as it does, bands of shadows which tend to break up a bleak expanse of wall into proportions pleasantly related to one another.

But the string has also a practical value. It is nearly always employed to form a finish to the masonry below the brickwork, when the façade of the lower part of a building is in stone (Fig. 6). The usual form is a flat band with a drip under, which throws off the water that runs down the brickwork before it streams over the stone and stains it. Another common position for a string is at cill level of the windows, the section employed often being that of a continuous moulded cill. String courses are never found in wood, but brick strings formed of two or three projecting courses are a common feature of many buildings (Fig. 7).

Modern Cornices

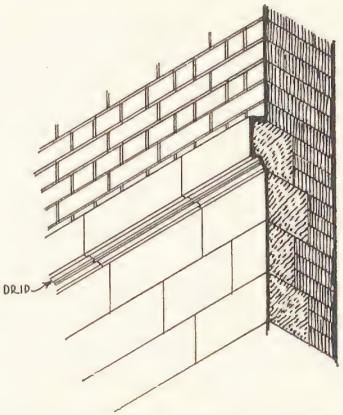


Fig. 6.—STONE STRING COURSE

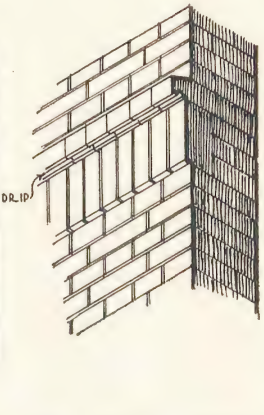


Fig. 7.—BRICK STRING COURSE

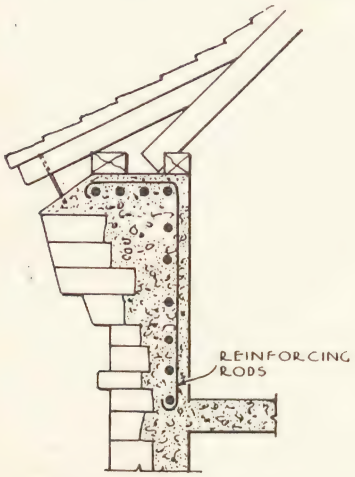
On modern concrete-and-steel buildings the classic cornice is rather out of fashion, and architects take the greatest liberties in designing suitable terminations to the walls. The large, overhanging, heavy stone cornice is difficult to construct safely on a building composed of skeleton steel beams and stanchions, and its appearance is an anachronism when it apparently projects several feet from the face of a wall probably not more than 9 in. thick. Fig. 8 illustrates two types of modern cornices. The first is from the recently erected tram terminus at Zurich, a building in the modern German style. The cornice is little more than the projection of the rough stone blocks with which the building is faced, the projection being built up on a backing of reinforced concrete which also acts as the plate to take the feet of the roof rafters, and it is the projection of these rafters which acts as the drip to throw the rain-water clear of the walls.

The second example is from a school building in America, where the cornice is little more than a slight thickening of the surface concrete of the wall. Fine concrete poured into a mould gives the profile, and the top is coped with pantiles.

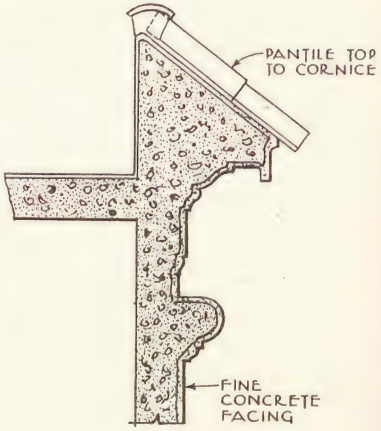
The practice of omitting the cornice entirely is logical in a modern building of steel and concrete, but unless an impervious material is employed for the face of the walls, a coping of sorts must be provided even if this is no more than a thin lead strip let into the surface and projecting sufficiently to throw off the water. Where no such precaution is taken, long streaks of dampness will soon give a derelict and neglected appearance to the building.

Materials

External cornices may be constructed of stone, brick, terra-cotta, wood, or metal. Metal cornices are ornamental features secured to the steel framework of the building, and the method has already been generally described in the articles on copper (page 303) and facing materials (page 362).



Modern cornice in stone and concrete from the Zurich tram terminus.



Reinforced-concrete cornice from a school in Sacramento, California.

Fig. 8.—TWO TYPES OF MODERN CORNICES

Stone Cornices

Small cornices are usually cut from a single stone, but all large ones have to be built up of courses overhanging and cantilevering down each other. Fig. 9 shows a single-stone cornice extending the full thickness of the wall below, and held in position by a blocking course (Fig. 10). At the back of the blocking course is an offset to take the wall plate and the foot of the roof rafters. Each stone of the cornice has a triangular sinking worked on it at both ends, and these sinkings, when the cornice is assembled, are filled in with cement grout, which acts as a key between the blocks. The upper surface of the stone is sloped forward to throw off the rain, and a raised quadrant of stone left at each joint. This is

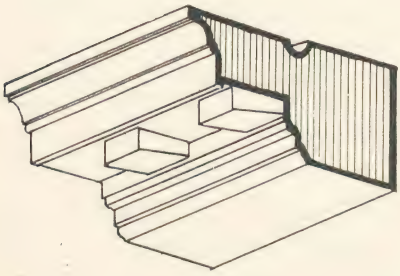


Fig. 9.—SINGLE-STONE CORNICE

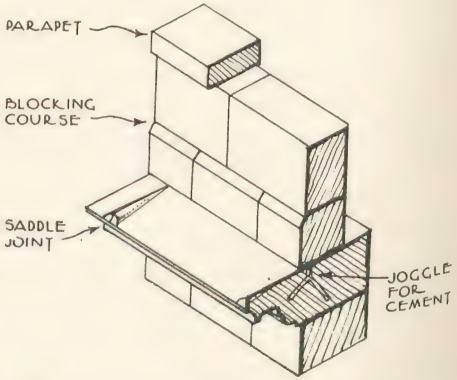


Fig. 10.—SINGLE-STONE MAIN CORNICE

called a saddle joint, and is formed to prevent the wet running into the vertical joint between the stones. A better but more expensive method is to cover the course with sheet lead.

Lead-covered Cornices

A sheet of 6-lb. lead is cut so as to turn down over the outer edge of the cornice, and either turned up 3 in. against the blocking course and tucked into a groove in the masonry, or burnt in with molten lead between the cornice and blocking course. The front edge is kept from lifting by being secured to lead dots, which are small conical holes drilled in the stonework (Fig. 11). The lead sheet is perforated over the hole and molten lead poured in to form a rivet-shaped " dot," which secures the sheet in place. Transverse joints in the lead covering are formed by welting in the usual manner.

Asphalte-covered Cornices

When heavy cornices project over public thoroughfares they are usually weathered back instead of forward, having a dished gutter cut in the stone along the back edge. Such cornices are usually covered with asphalte, and worked without saddle joints between the stones. To secure the asphalte a groove is cut along the top near to the outer edge of the cornice, and a second about 3 in. up the face of the blocking course. The molten asphalte is spread over the stone and dished gutter, and pressed into the groove on the front edge, as well as being turned up against the blocking course and into the vertical groove. The vertical joints are thus protected from the wet, and an asphalte gutter formed to convey the rain-water to the down pipes. In very high-class work a thin strip of 4-lb. or 5-lb. lead is laid under the asphalte and dressed down over the edge of the top moulding to act as a drip, since the asphalte cannot be carried down the front, but this precaution is not really necessary except in cases where asphalte is employed to cover a cornice weathered forward instead of back. Fig. 12 shows an example of a cornice where the top stone is slightly dished at the joint with the blocking course, and the asphalte tucked under with the blocking course laid on top.

Cramps

The angle stones of cornices are frequently tied in with cramps as well as by the cement joggles already described (Fig. 13). A groove or chase of the

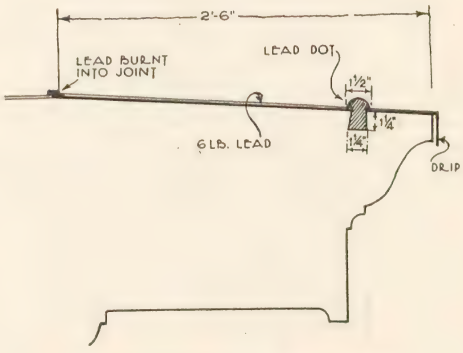
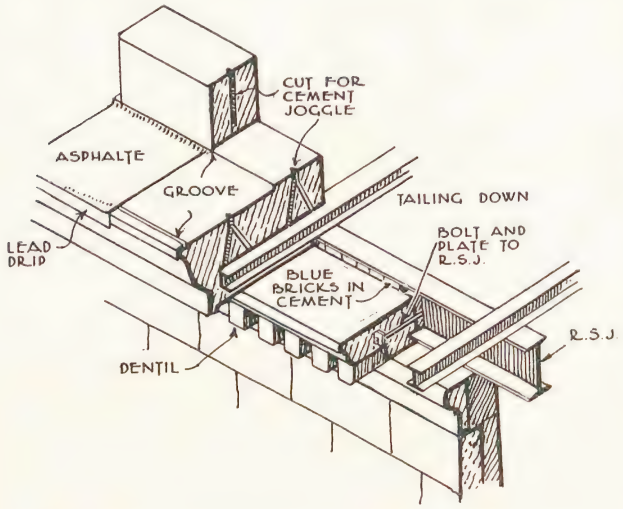


Fig. 11.—LEAD-COVERED CORNICE



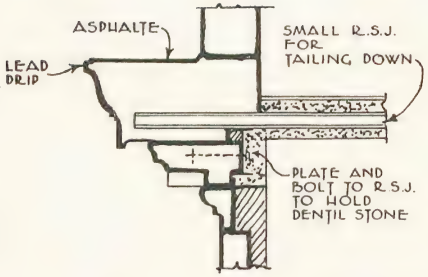


Fig. 12.—STONE CORNICE IN STEEL-FRAME BUILDING

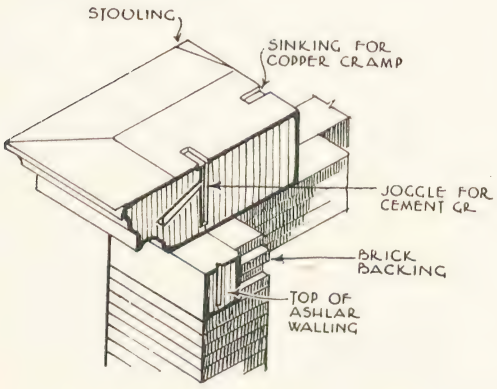


Fig. 13.—ANGLE OF STONE CORNICE

width and depth required is cut in the stone, and at each end a mortice hole sunk of sufficient depth to take the turned-over end of the cramp, which should fit exactly when tapped lightly into place with a mallet. Melted brimstone or cement is then poured in, and flushed off smooth with the top surface of the stone.

Iron and Slate Cramps

Iron cramps or dowels should never be employed unless thoroughly galvanised, or they will rust, and in expanding split the stone. Slate cramps when used are about 1 in. deep, and cut like a double dovetail. They are let into the top of the stone and secured with cement.

Modillions

In large cornices composed of more than one stone the modillions should be worked out of the solid upper portion. If a joint is placed immediately over a row of modillions there is a tendency for them to crack off and fall, should any settlement of the cornice take place. The temptation to work the modillions separately from the upper stone is great, since there is a considerable saving in stone and labour, but it is a bad practice and constitutes a real danger

if the cornice overhangs a street.

Bedding

All cornice stones should be edge bedded except corner stones, and these should be specially selected and laid on their natural bed.

Tailing Down

Fig. 12 illustrates a method of taking back a heavy, built-up cornice on a thin wall, such as might be found on a modern steel-framed building. The bed mould is secured to the main horizontal steel beams by bolts and plates let into the stone and run with cement, and the large overhanging corona stone drilled out to take the ends of the tailing-down irons, which are small steel joists cantilevered over the main beams. The vertical joints are still further secured by running cement into the joggles cut into the faces as shown. Pinning up between the steel and stone is done with blue bricks packed into the space below the upper flange of the main beams, and all other spaces and interstices filled in with fine concrete. Fig. 14 illustrates another method suitable for a single-stone cornice. Here the back of the stone is roughly shaped to take the steel joist, and provided the steel is well packed round with fine concrete it forms a satisfactory fixing. Such a cornice requires a good blocking course to tail it down, and the stone must be temporarily strutted on its outer edge from the scaffolding until such time as sufficient top weight has been built up on it to balance it.

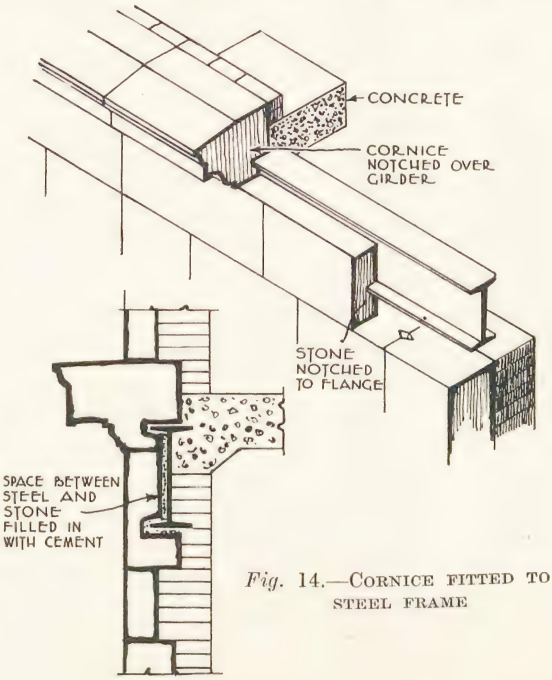


Fig. 14.—CORNICE FITTED TO STEEL FRAME

If the superimposed weight of a blocking course is not enough to hold down the cornice, the method shown in Fig. 15 should be employed. Here the cornice rests on a pair of steel joists set slightly apart, and a bolt with a top and bottom plate is fixed between each stone. The top plate is let into the back edges of two adjacent stones, and the bottom one drawn up tightly against the under sides of the flanges of the beams. In this case, also, the usual joggles are cut in the vertical stone faces and run with cement.

Working Mouldings

The mouldings on a modern cornice are usually worked by a machine in the stonemason's yard. These machines to-day are brought to such a stage of perfection that almost all the usual labours on a stone can be executed by them. There are, however, certain forms and mitres that still have to be cut by hand. Where old work has to be repaired and matched it is still economical in some places to have the blocks of stone delivered, and worked by hand on the bankers at the job.

There is no standard method for handworking stone, each variety requiring its own special treatment. A mason will work a sandstone differently from limestone, and even Bath and Portland stonemasons employ each their own methods, but the general principles are the same and may be briefly described.

The group of mouldings on a cornice formed from a single stone is worked in stages, each sinking in the face of the stone preparing the way for the next labour. The block is first placed upside down on the banker, with the natural bed laid in the direction required, and the profile of the cornice, which has been cut on a zinc template, applied to one end and roughly marked on it. A chamfer line is then drawn across the face of the bed moulds, and the unwanted block of stone (marked B on Fig. 16) is then cut away. The fillet lines are then produced to cut the chamfer line as shown at C and A. The several checks which mark the arris lines for the cavetto and hollow of the cyma are next cut. The hollows being worked out, small tangents are cut which are finally worked into the convex forms of the cyma or ovolo. The last work is to form the crowning feature and fillet at M. When all is complete the sinking R is made, and the drip formed at the edge of the corona. The stone is then turned over and the weathering on the upper side worked off, with or without the saddle joints as required.

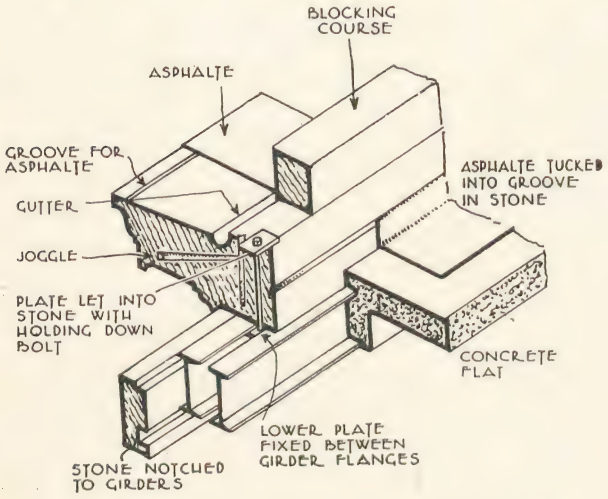


Fig. 15.—CORNICE ANCHORED DOWN WITH BOLTS

Return Ends

On a return end the mouldings are completely worked through on one side, and a mitre line scribed which will give the correct outline for the return moulds on the

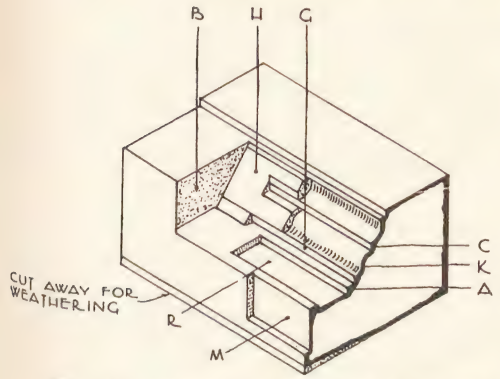


Fig. 16.—METHOD OF WORKING A CORNICE BLOCK

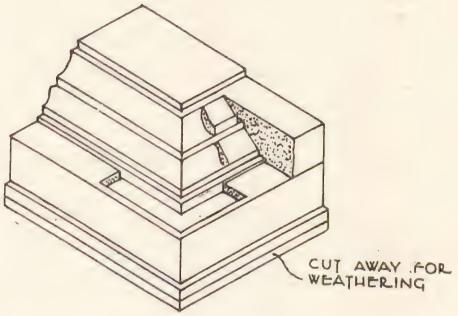


Fig. 17.—METHOD OF WORKING A RETURN AT ANGLE

other face. To scribe this mitre one method is to hold a straight-edge in position, the external angle being found by placing a square on the bed of the stone and keeping the flat surface of the straight-edge pressed close against the blade of the square (Fig. 17).

The sinkings in the vertical sides of the stone for forming the cement joggles should be worked before the stones leave the banker, as also any sinkings for cramps and dowels.

Lewis Bolts

All large stones must have mortice holes sunk into their upper surfaces, in positions which will subsequently be covered by other stones, to take the lifting hook known as a lewis bolt. (For a description of the lewis, see page 349, Vol. III.)

Terra-cotta Cornices

Terra-cotta is frequently used in place of stone to form a cornice, especially in industrial areas where the acids in the atmosphere would cause masonry to decay. Terra-cotta as a facing material is described on page 346. Fig. 18 illustrates a built-up cornice and frieze such as might be used on a large store or cinema. The main walling is built in brickwork, and a chase of several courses left to take the frieze, which consists of plain blocks of terra-cotta filled in with fine concrete and then fitted into position. This work is best done at the same time as the bricklaying is carried on. The bed moulds of the cornice itself are built up of small sections of terra-cotta, and the overhang is supported on a 5-in. by 3-in. section of rolled-steel joist tailed down into the wall with a $\frac{5}{8}$-in. bolt having a 6-in. by 6-in. by $\frac{1}{2}$-in. base-plate at the bottom. This cantilever carries a 3-in. by 3-in. by $\frac{3}{8}$-in. T-iron upside down, and to this is bolted the reinforcement stirrups which support the terra-cotta sections of the

cornice soffit. The upper portions of the corona are also tied back to this T-iron with hooked reinforcement bars as shown. When the reinforcement is in position, the whole of the back of the terra-cotta sections is filled in with fine concrete to form a compact mass. The top of the cornice is weathered back towards the main wall and flashed with 6-lb. lead turned up against the brickwork, and secured with a cover flashing tucked into the horizontal joint.

Fig. 19 shows a simpler form of terra-cotta cornice suitable for a building entirely faced with the material. The projection is slight, and no cantilever bracket is needed, the terra-cotta being held in place by means of reinforcement bars spaced at frequent intervals and hooked at ends. The lower end is secured under the flange of the structural joist, and is thus firmly anchored down.

Fig. 20 illustrates yet another type of cornice. This is a finish under an eaves where the roof covering projects beyond the face of the terra-cotta. In such a position a gutter would be difficult to fix in a satisfactory manner, and as an alternative a secret gutter is formed in the slope of the roof. Such a gutter is invisible from below, and serves to catch the major part of the rain-water and convey it to the down pipes. The cornice itself is supported, like the previous example, by reinforcing bars, tied down to the main steel framing of the building.

Brick Cornices

Many buildings faced with brickwork have brick cornices. In the simplest cases these are merely projecting bands of brickwork varied by the introduction of tiles. But specially moulded bricks are obtainable whereby the more elaborate cornice profiles can be executed. There are many examples in old work of cornices being built up in the true classic proportions by means of moulded bricks, and in these examples it will be found that brick and terra-cotta are intermixed, the latter being used to reproduce mouldings upon which ornamental features were carved as well as dentils and modillions.

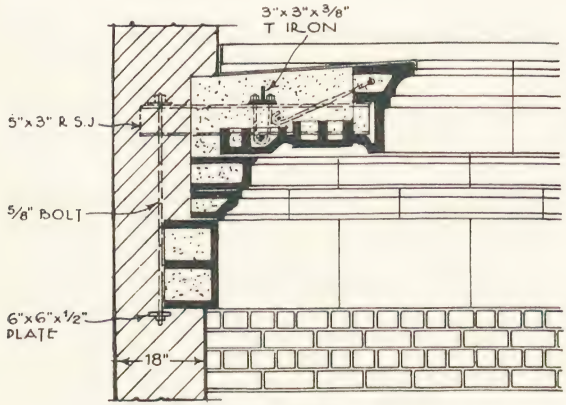


Fig. 18.—BACK OF TERRA-COTTA BLOCKS FILLED IN WITH CONCRETE

Fig. 21 shows a typical example of a Doric brick cornice, complete with entablature and pilaster cap. It is almost entirely built up of a

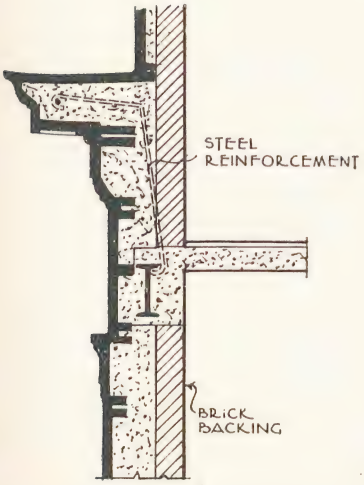


Fig. 19.—A TERRA-COTTA CORNICE SUITABLE FOR A BUILDING ENTIRELY FACED WITH THE MATERIAL

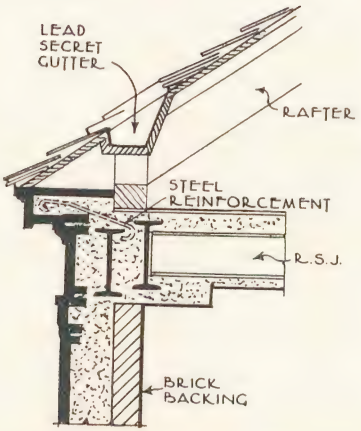


Fig. 20.—DETAIL OF AMERICAN PRACTICE WITH TERRA-COTTA CORNICES

smooth type of brick which can be cut and rubbed easily to the shapes required.

An English eighteenth-century brick cornice from London is shown in Fig. 22. Here the cornice is composed of plain and moulded brickwork with fine joints, and the ornamental modillions are carved from brick lumps burnt in a similar manner to the general walling.

Cement Flashings

It is necessary to protect the upper surfaces of all projections in a brick cornice with a weathering of cement, and the whole should be well pointed up on completion to prevent wet from penetrating and causing the mouldings to crumble.

External Wood Cornices

External wooden cornices are constructed for similar purposes to stone ones, and the rules for obtaining the various proportions and projections apply equally to them.

One of the simplest types is shown in Fig. 23. Here the topmost moulding is provided by the profile of a stock-pattern cast-iron gutter, fixed to the 1½-in. fascia board. The fascia is nailed to the cut ends of the ordinary roof rafters, and a small moulding planted on immediately below the gutter. The lower back edge of the fascia board is grooved throughout its length, and into this is tongued one edge of the soffit

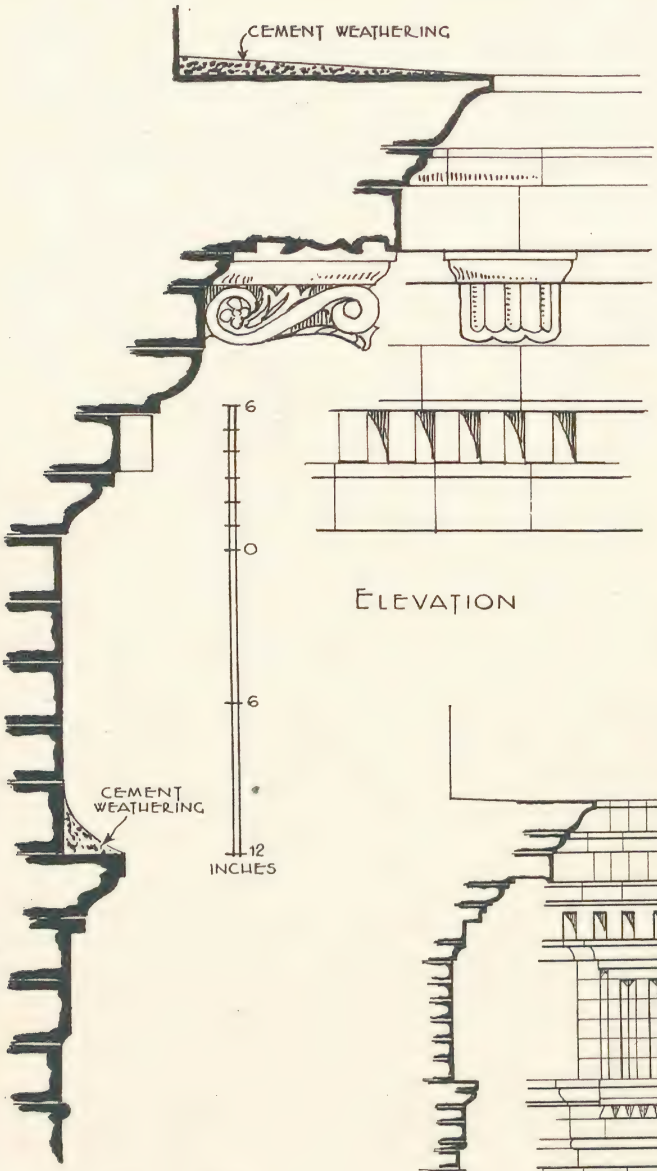


Fig. 22.—BRICK CORNICE — AN EIGHTEENTH-CENTURY EXAMPLE IN LONDON

board. For a wider overhang, two, or even three, soffit boards are grooved and tongued together according to the width required. This joint at the edge of the fascia provides the drip moulding, which in this case is not so necessary as in a stone cornice, since the gutter also carries off the water.

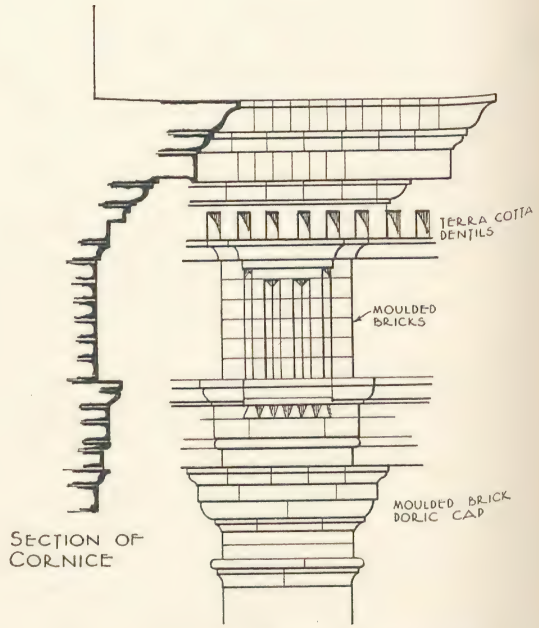


Fig. 21.—ITALIAN MOULDED-BRICK CORNICE

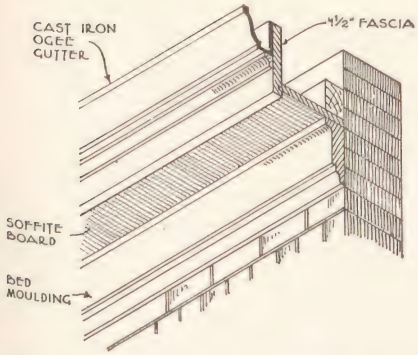


Fig. 23.—SIMPLE WOOD CORNICE AND GUTTER

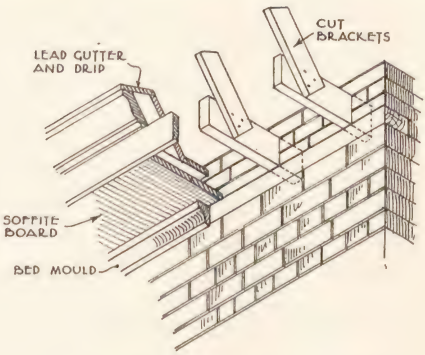


Fig. 25.—BRACKETED WOOD CORNICE

The back edge of the soffit board is screwed to a fixing batten spiked into a joint in the brickwork, and the lower edge of the cornice completed with a bed moulding fixed directly to the brickwork.

Another type of cornice is shown in Figs. 24 and 25, where the cornice is supported on brackets projecting from the wall, and the gutter formed behind the top edge by means of a lead flashing. The brackets are constructed from rough timbers of 4-in. by 2-in. and 4-in. by 3-in. sizes, which often rest on a second wall plate fixed in the outer face of the wall. This plate is also useful for securing the lower mouldings of the cornice, as shown in the two illustrations.

A modillion cornice is shown in Fig. 24, where the modillions are simple cut brackets spiked through to the wall.

Rolled-steel-joist Brackets

In many modern buildings the wood brackets are superseded by sections of rolled-steel joists or angle irons, spaced at 2-ft. centres. These can be built directly into the brickwork, and eliminate the danger of the built-in end of the bracket becoming decayed. The method is a more expensive one, and requires a larger amount of labour in cutting and fitting wood bearers and brackets into the exposed parts of the steelwork, but

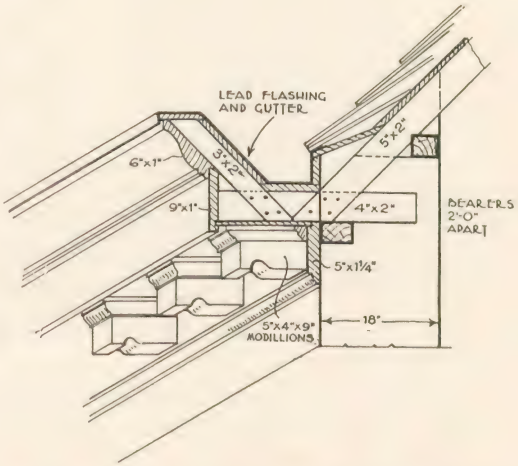


Fig. 24.—BUILT-UP WOOD CORNICE ON BRICK WALL

it should be employed in all large cornices. All concealed woodwork should be treated with a preservative, especially the ends built into the wall.

Painting

Wooden cornices depend entirely upon maintenance for their existence, and need to be frequently painted and examined to see that the lead flashings remain watertight. A neglected cornice, where the water has been allowed to soak unseen into the supporting brackets, may appear sound, but a careful examination should always be made of the whole length. A sudden wind has often caused the stripping of whole lengths of wooden cornice from rotten brackets, the cornice itself being in perfect condition.

Internal Wood Cornices

Internal cornices are often employed in connection with wood panelling where the walls are unplastered. The panelling is fixed to backing strips on the brickwork, and the wood cornices built up upon it. Fig. 26 shows a simple cornice formed with a deep cove rebated to the top rail of the panelling. This cove is still further secured to the wall by means of cut wood brackets 1 in. thick, fixed to the wall plate or spiked to the first-floor joists. The upper edge of the cove is secured against a $\frac{3}{4}$-in. by 2-in. bevelled ground, which also acts as a key to the ceiling plaster. This strip is in turn covered with a rebated moulding which forms the upper moulding of the completed cornice.

A more elaborate type of cornice is shown in Fig. 27. Here a 4-in. by $1\frac{1}{2}$-in. moulding is tongued into the top rail of the panelling, and the cornice built up upon it out of $\frac{3}{4}$-in. and 1-in. boards tongued and grooved together at the joints. The crowning cyma recta mould, in imitation of the stone form, is run out of a piece of 6-in. by 1-in. boarding, and housed into the vertical face as shown. The finish against the plaster ceiling is executed in the same manner as the former cornice, with a strip nailed to the joists to act as a plaster stop. This cornice is still further enriched by a row of modillions cut from blocks 4 in. by 2 in. by 2 in., and screwed to the flat faces above and behind them. The joint between the top of the modillion and the soffit is covered with a small moulding mitred round each modillion, and along the back between them.

Plaster Cornices

There are several different materials in general use for running plaster cornices, and the majority have a base of calcined gypsum, usually known as plaster of Paris. This is often mixed with other substances to produce extra hardness, sharpness of outline, or ease of working.

Materials

The best-known varieties are Keene's, "Parian," "Sirapite," and various kinds of selenitic plasters.

One of the chief advantages of using these plasters is their rapidity in setting and drying after being run ; their defect, the readiness with which condensation takes place on their hard surfaces. But for cornice work, the advantages outweigh the disadvantages.

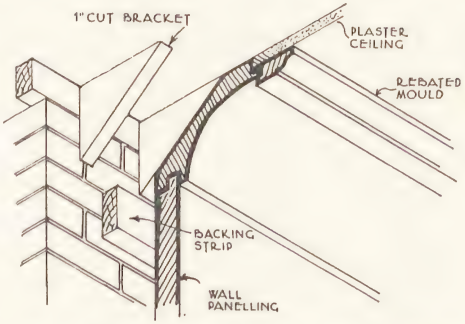


Fig. 26.—SIMPLE TYPE OF WOOD CORNICE

Internal cornices are run in plaster or special cements on a backing or " pricking coat " of Portland cement and sand. Small cornices are run directly into the angles of the walls and ceiling (Fig. 28), but larger and more elaborate ones require a backing of wood bracketing and lathing to prevent the mass of plaster, especially at the corners, from becoming dangerously heavy (Fig. 28A). Normally the profiles of internal plaster cornices should be kept as flat as possible, but in large buildings they frequently resemble stone external forms. Such cornices require support, which is provided by using 1-in. shaped wood brackets cut to the rough outline of the cornices, secured to the joists and then lathed over. A backing coat $\frac{3}{8}$ in. thick is then applied and is scratched to form a key for the final coat, composed of equal quantities of lime putty and plaster of Paris.

Running Cornices

To run a plaster cornice, a zinc template is first cut to the reverse profile of the mouldings required. This is mounted on a rough wooden frame so splayed at the edge as to allow the zinc to project. This bracket is screwed to a flat wooden board called the slipper, and is further steadied by a handle ; when completed the tool is called a horse (Fig. 29). Wood laths, each about 2 in. by $\frac{3}{4}$ in., are nailed to the ceiling and the wall to act as guides for the horse, which slides between them as shown

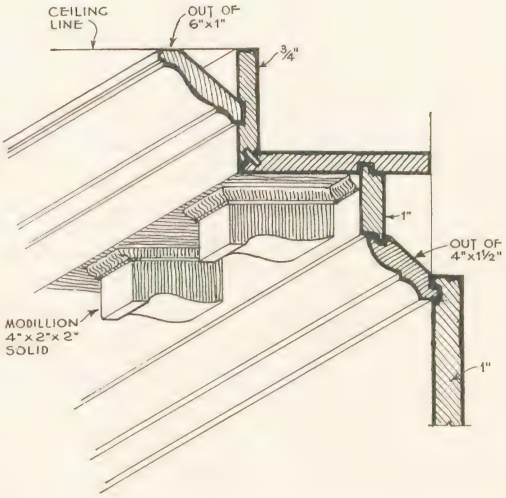


Fig. 27.—BUILT-UP INTERNAL WOOD CORNICE

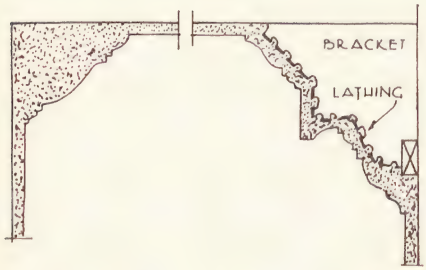


Fig. 28.—PLASTER CORNICE ON WALL

Fig. 28A.—PLASTER CORNICE ON BRACKETING

in Fig. 30. The upper lath is called the nib guide, and the lower the slipper guide. By drawing the zinc template over the finishing coat of plaster, the exact profile of the cornice required is produced.

By this method any length of straight cornice can be run. On reaching the angles the horse is removed, and the mitre generally worked by hand or with special tools.

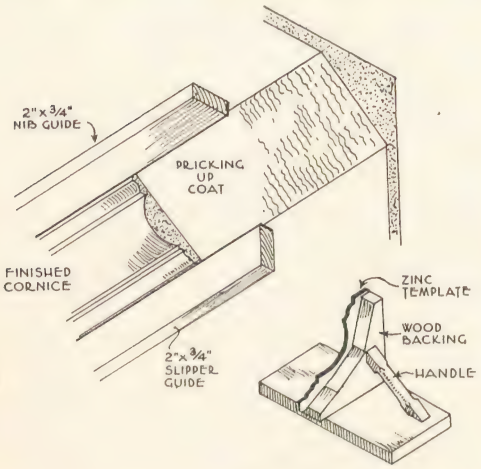
Plaster cornices attached to steelwork are built up on bracketing, as shown in Fig. 31. Horizontal bearers are bolted to the webs of the steel joists, and rough brackets nailed to these at intervals to take the lathing.

In many types of buildings, such as theatres and cinemas, wood lathing for plaster cornices is not permitted, and the joists in these cases must be covered with expanded metal lathing bent to the approximate shapes. Cornices run against concrete walls and floors are also supported on expanded metal lathing held in position by iron brackets made from $\frac{1}{2}$-in. by $\frac{3}{8}$-in. flat bars, split and pinned in at the ends. Cornices are run on expanded metal in two-coat work in a similar manner to wood lathing.

Fibrous Plaster

But to-day greater use is being made of fibrous plaster, especially where speed of construction is important, since the long, dry lengths of ready-moulded and ready-enriched cornice are easy and quick to fix.

A fibrous-plaster cornice is made up of laths and a canvas called scrim as a background, and the plaster of Paris run on to the material, the process being known as stick-and-rag work.



Detail of horse.

Fig. 29.—METHOD OF RUNNING PLASTER CORNICE

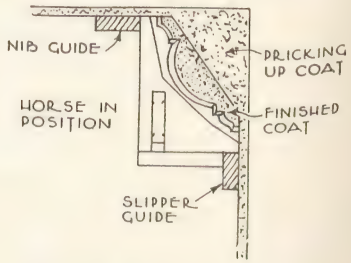


Fig. 30.—METHOD OF USING HORSE

Fig. 31 shows a typical sectional view of such a cornice. The only fixing required is a deal ground on the ceiling, and another on the wall. A lath is cast into the extremities of the cornice, and the whole secured in position by a screw at top and bottom. On long lengths a batten is frequently fixed as shown, at intervals of about 1 ft. 6 in. along the back of the cornice, and covered with the canvas and plaster. These battens act as stiffeners, and their presence generally indicates that the cornice has been supplied by a first-class firm.

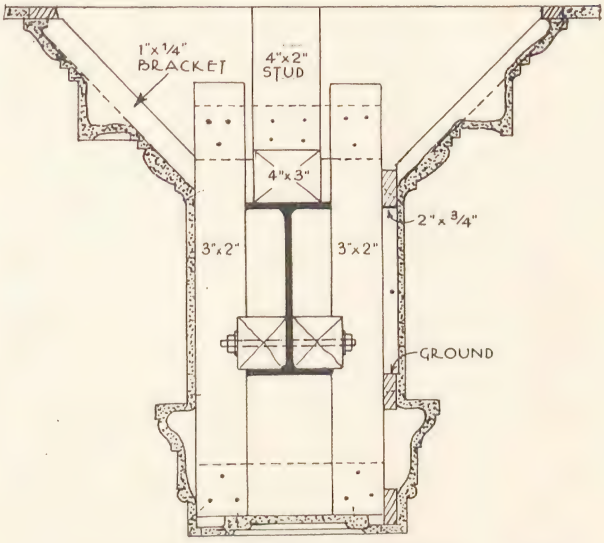


Fig. 31.—PLASTER CORNICE AND BRACKETING ROUND ROLLED-STEEL JOIST

Fig. 32 illustrates a cornice fixed to a concrete ceiling and wall by means of grounds, the upper ground acting at the same time as a stop to the ceiling plaster. This type of cornice, with a deep cove and long spread at the upper mouldings, is very effective in a moderate-sized room, where a heavy cornice would be out of scale.

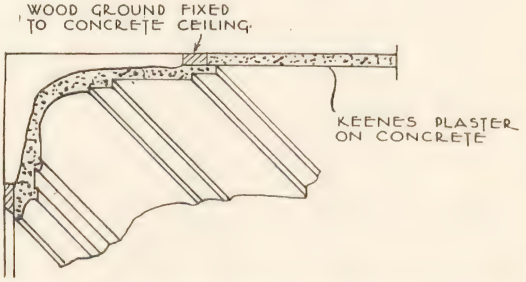


Fig. 32.—FIBROUS CORNICE ON CONCRETE WALL

Fig. 33 shows the same type of cornice fixed to a brick wall and wooden joists. Here the ceiling is composed of

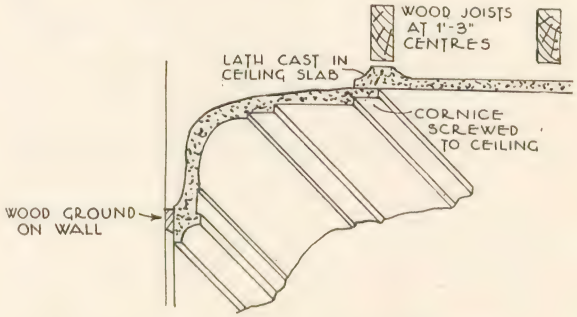


Fig. 33.—FIBROUS CORNICE ON WOOD JOISTS

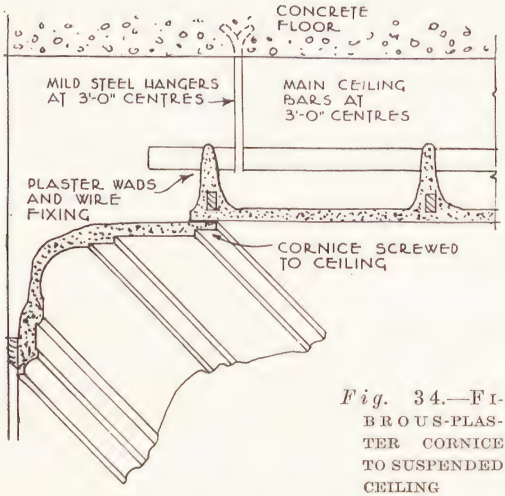


Fig. 34.—FIBROUS-PLASTER CORNICE TO SUSPENDED CEILING

precast slabs screwed to the joists, the upper edge of the cornice being screwed through the ceiling slab into the joist above.

Another type of construction is shown in Fig. 34. Here a fireproof building, such as a cinema, precludes the use of wood construction, and the ceiling and cornice are slung from the concrete floor by means of mild-steel hangers and ceiling bars. The ceiling is secured by means of plaster wads, the slabs being first wired up to the bars, and the wires then wrapped round with canvas dipped in plaster of Paris, the whole, when set, forming an excellent key.

A more ambitious plaster cornice is shown in Fig. 35. This type would be suitable for a dance hall or cinema foyer. The lighting is

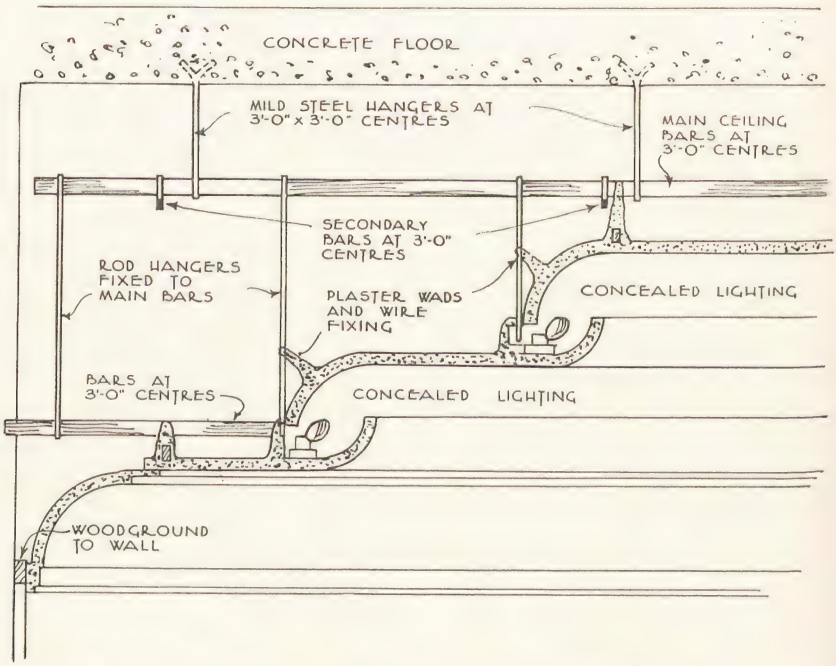


Fig. 35.—FIBROUS-PLASTER CORNICE WITH CONCEALED LIGHTS

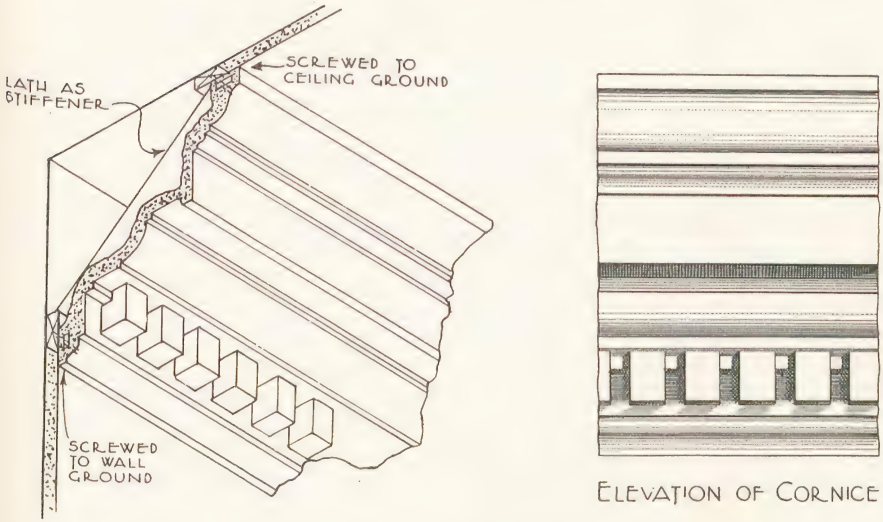


Fig. 36.—FIBROUS-PLASTER CORNICE WITH DENTIL ORNAMENT

concealed in long, plaster gutters in two tiers, and the whole construction tied up to the concrete floor above by means of rods and ceiling bars. No wood is used in the construction, the various parts of the cornice being secured by means of the plaster wads already described.

QUESTIONS AND ANSWERS

What is a Saddle Joint ?

A joint made by placing together the quadrants on the upper surfaces of two cornice stones. It prevents water from running into the vertical joint between the stones.

How is a Fibrous-plaster Cornice made up ?

It is made up of laths and a canvas scrim background. Plaster of Paris is run on to the material.

What precaution is necessary with the Upper Surfaces of all Projections in a Brick Cornice ?

Protection with a weathering of cement.

ROOF CONSTRUCTION

PART V.—FLAT ROOFS—TRIMMING

IN practice flat roofs are formed with timber, concrete and steel reinforced concrete, or hollow tiles as a base, and covered with asphalte lead, copper, or zinc, or concrete slabs over asphalte, or asbestos-cement tiles on asphalte. The construction is similar to floor construction, but a slight fall is necessary to drain off the water.

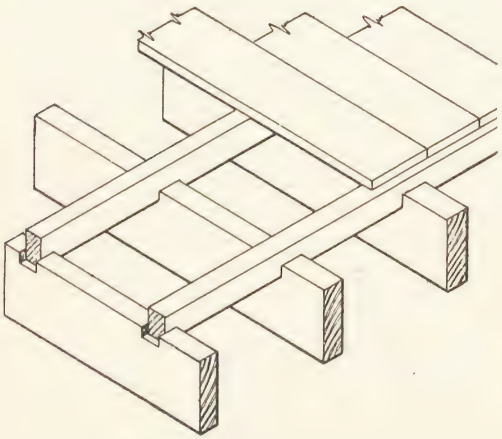


Fig. 1.—FLAT ROOF—JOISTS PARALLEL TO FLOW

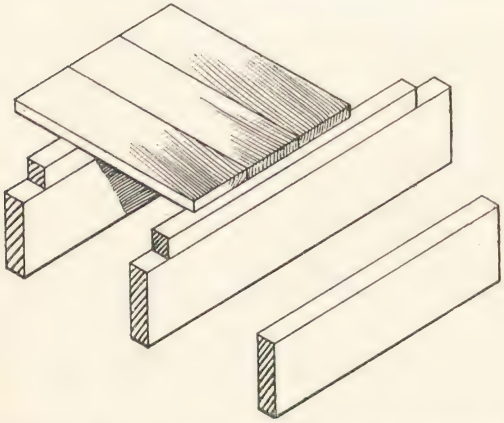


Fig. 2.—FLAT ROOF—JOISTS AT RIGHT ANGLES TO FLOW

Timber Construction

When timber is employed the joists are furred to falls (Fig. 1). Where the span of the joists exceeds about 16 ft., rolled-steel-joist binders are introduced to form an intermediate support for the joists. For lead-covered flats, the roof is given a fall of $1\frac{1}{2}$ in. in 10 ft., or 4°. The boards should run in the direction of the flow, because if placed at right angles to it, and the boards should warp slightly, hollows would form in which the water may lie (Figs. 1 and 2). For good-class work the boarding should be in narrow widths, and $1\frac{1}{4}$-in. nominal thickness, and the roof covered with felt to give a smooth surface for the lead or other covering.

Drips

The joint along the end of the lead sheet is formed by

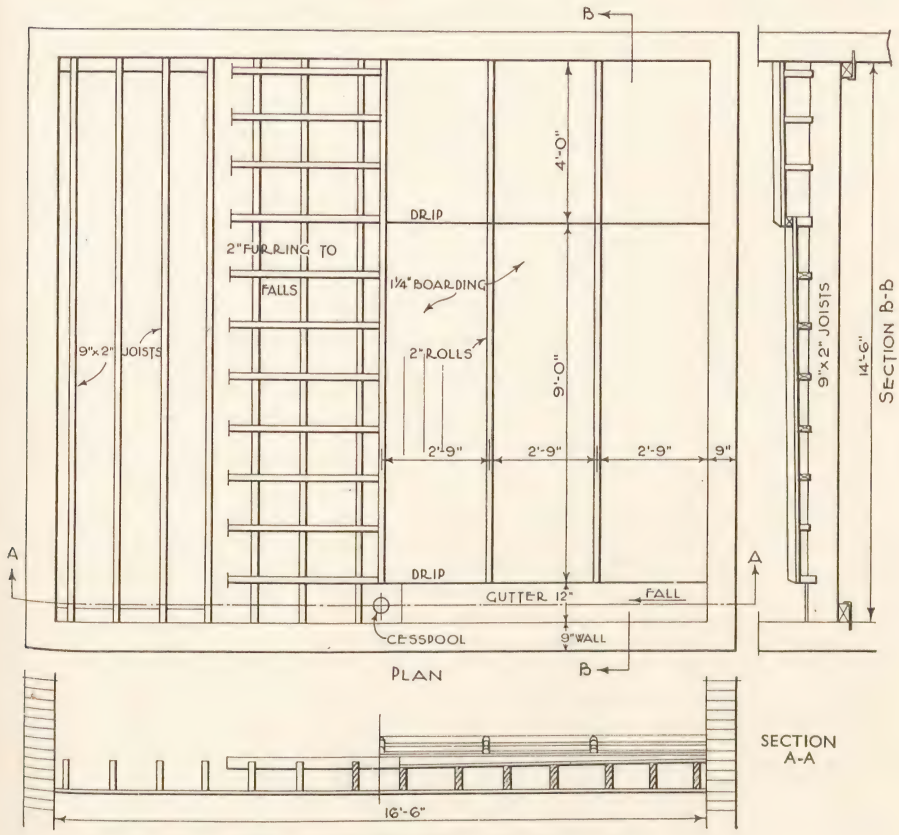


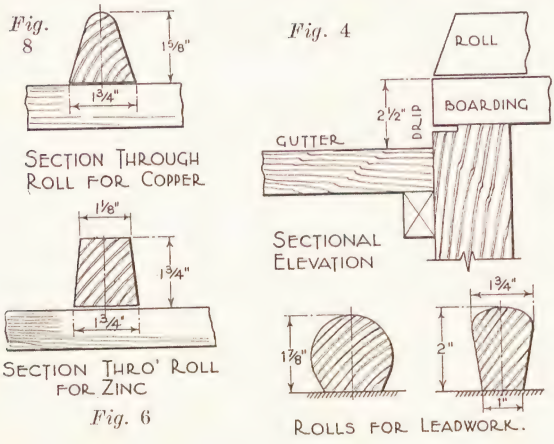
Fig. 3.—PREPARATION FOR LEAD FLAT

means of a *drip*—an abrupt change in the level of the roof, usually $2\frac{1}{2}$ in. deep. The face of the drip may be vertical (see Fig. 4), or an angle fillet may be introduced.

The end of the boarding at the top is rebated to a depth equal to the thickness of the sheet, and a width of 1 in. or $1\frac{1}{2}$ in. The upper end of the lower sheet is dressed over the drip and turned down into the rebate, and fixed with copper nails. The upper sheet is next dressed down over the drip, and is either finished about $\frac{1}{2}$ in. short of the lower flat or carried down and dressed about 1 in. on the flat below. The amount of lead required to form a $2\frac{1}{2}$-in. drip is 7 in., and this amount, deducted from the maximum length of sheet it is desirable to use, i.e. 10 ft., gives the distances between the drips or length of bay at 9 ft. 5 in.

Rolls

The joint along the edge of the sheet and parallel to the fall is formed by means of a roll, over which the lead sheets are dressed (see Fig. 5). The edge of one sheet, or *undercloak* as it is called, is dressed about two-



Figs. 4, 5, 6, *and* 8.—DETAILS OF ROLLS FOR SHEET METAL

thirds round the roll, and copper nailed. The adjoining sheet, the *overcloak*, is then dressed over the roll, covering the edge of the first sheet and finishing 1 in. on the flat. Allowing 3 in. for the undercloak and 7 in. for the overcloak, the maximum distance from centre to centre of the rolls is 2 ft. 10 in., which allows two sheets being cut in the width of the roll.

Zinc Roofing

For zinc work the common sizes of sheets manufactured are 7 ft. by 3 ft. and 8 ft. by 3 ft.

Allowing 6 in. for the drip and 3 in. for the roll, the size of the bays will be 7 ft. 6 in. by 2 ft. 9 in.

The rolls are trapezoidal in form, splayed on their sides from $1\frac{5}{8}$ to $1\frac{3}{4}$ in. at the bottom to a width of $1\frac{1}{8}$ in. at the top, the height being the same as width at bottom (see Fig. 6).

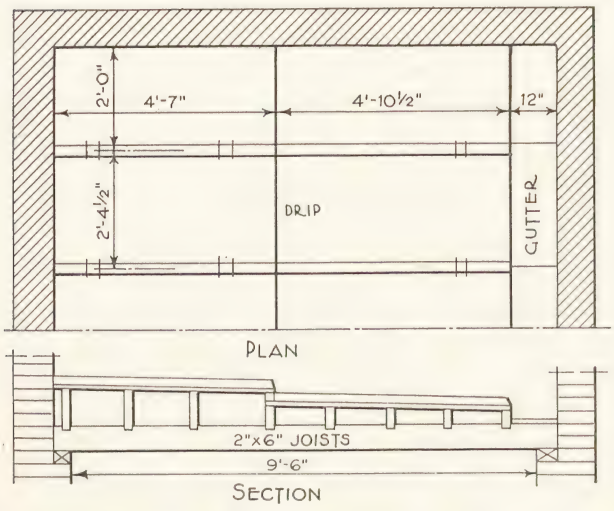


Fig. 7.—PREPARATION OF ROOF FOR COPPER COVERING

Copper Roofing

For copper roofing the sheets employed measure 5 ft. 3 in. by 2 ft. 8 in., and 4 ft. by 3 ft. 6 in., both having the same area. After making allowances for roll and drip, the bays will measure 4 ft. $10\frac{1}{2}$ in. by 2 ft. $4\frac{1}{2}$ in. when using a 5-ft. 3-in. by 2-ft. 8-in. sheet (Fig. 7). The rolls are made conical shape in section, measuring $1\frac{3}{4}$ in. at the bottom and $1\frac{5}{8}$ in. or $1\frac{3}{4}$ in. in height (see Fig. 8).

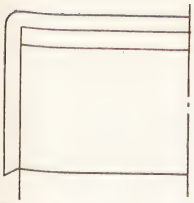


Fig. 9.—ASPHALTE APRON WITH UNDERCUT DRIP

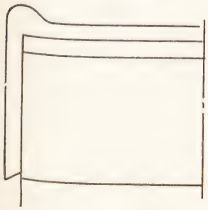


Fig. 11.—ASPHALTE FINISH AT VERGE

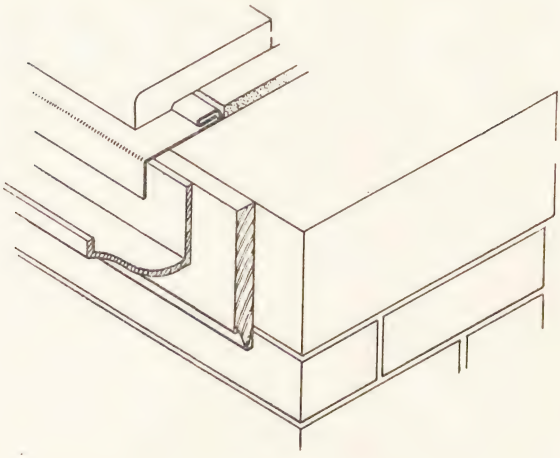


Fig. 10.—ASPHALTE DRESSING TO WELTED LEAD OR COPPER APRON ON REBATED EDGE

Further details of copper roofing are given on pages 289-303, and on Data Sheets 16 and 17.

Asphalte Roofing

This material can be laid on concrete or boarding ; when laid on boarding an underlay of felt must be employed, but the use of wire or expanded metal lathing in addition is not considered essential. For flat roofs the surface should be finished to a fall of 1 in 10. On sloping roofs the surface should be formed with grooves to provide a key, as the material is apt to run if exposed to the sun. The grooves are formed by fixing $1\frac{1}{2}$-in. by $\frac{3}{8}$-in. battens horizontally along the roof at 18-in. centres, and then rendering the surface level with the top of the battens in cement and sand (1 to 2). The battens are removed after the cement has set, leaving grooves in the surface. Where a flat roof finishes with an eaves gutter the asphalte is dressed over on to the face of the wall to form an apron (see Fig. 9), the lower edge being splayed back to form a drip. An alternative method is to dress the asphalte to a welted lead or copper flashing on a rebated edge of the flat, the asphalte being set back $\frac{3}{4}$ in. from the edge (see Fig. 10). Where verges occur on a concrete pitched roof, the edge is slightly tilted to divert the water from the edge (see Fig. 11).

Junction of Roof with Lantern Lights

Where a flat roof abuts against a lantern light, a curb is formed in concrete or wood, the asphalte carried up the face of the curb and finished

Fig. 12

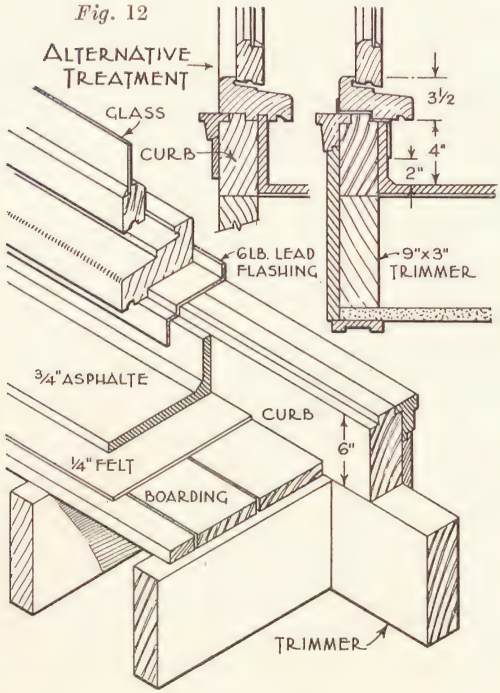


Fig. 13.—TREATMENT OF TIMBER ROOF ABUTTING LANTERN LIGHT

glass are now largely used in the construction of lantern lights.

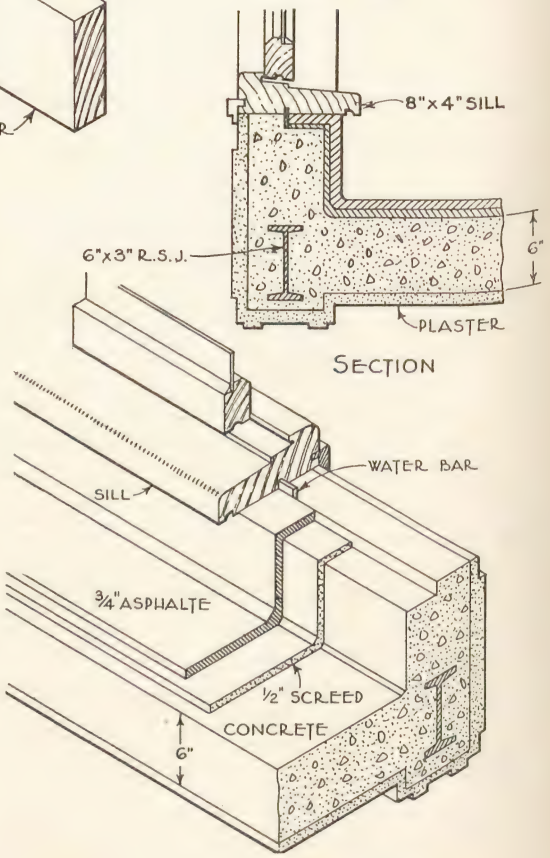
Steel Construction

Fig. 15 shows a lantern light in all-steel construction. The angle shafts are $2\frac{1}{4}$ in. square, and the metal $\frac{3}{16}$ in. thick; the cill is also of the same section. The cill is fixed to the concrete curb by means of a lug, as shown, or by the use of a coachscrew, where the curb is formed with timber.

in a groove in the under side of the cill (see Fig. 12), or it may finish against the under side of the cill with the addition of a lead flashing, a groove being formed in the cill for the purpose (Fig. 13). For a concrete curb the asphalte is taken up the face of the curb under the cill, and finished against the water bar (see Fig. 14).

Steel and concrete and

Fig. 14 (*below*).—TREATMENT FOR CONCRETE ROOF ABUTTING LANTERN LIGHT



" Glass-crete "

The use of glass prisms embedded in concrete gives a strong construction which allows considerable carrying power over large spans. The glass units are produced in dimensions to conform to structural requirements as to thickness and weight, depending on the type of structure. The use of concrete permits of greater possibilities, and the older methods of glazing, which would not meet the higher standard of modern practice, have been superseded.

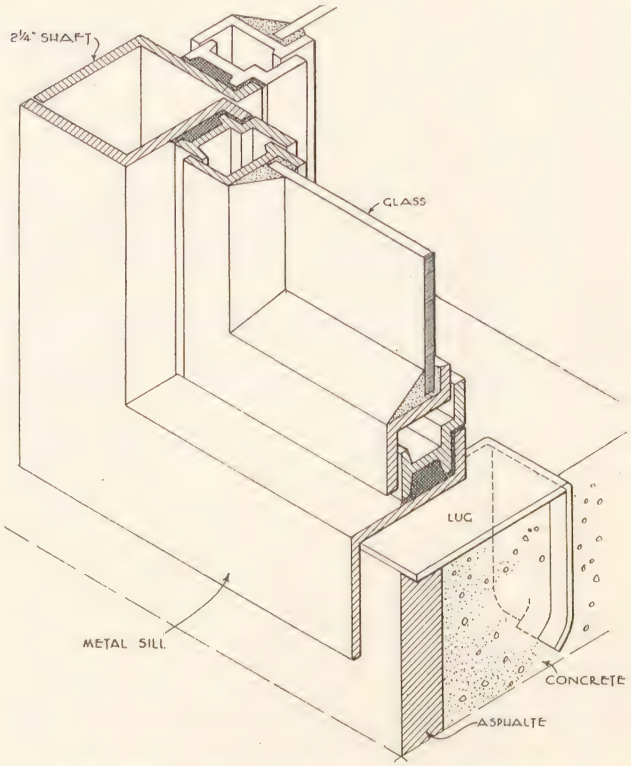


Fig. 15.—LANTERN LIGHT IN ALL-STEEL CONSTRUCTION

All the disadvantages which arose from the use of wrought iron are removed by the use of reinforced concrete. In addition, there are no surfaces to rust,

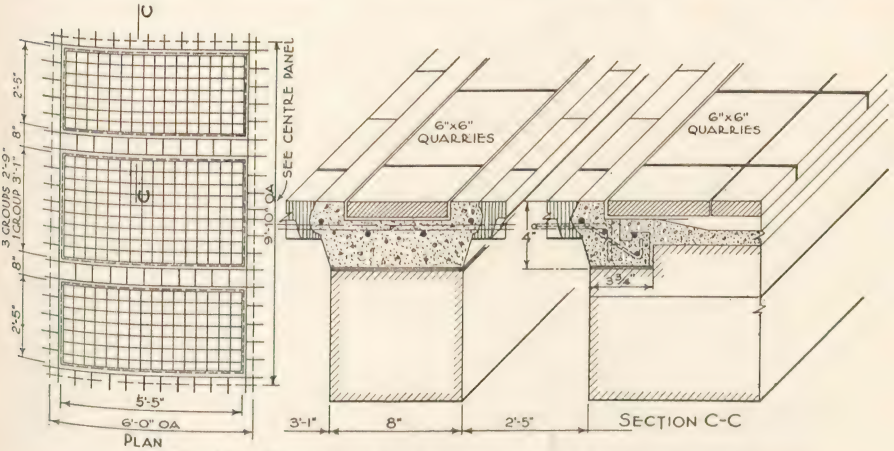


Fig. 16.—DETAIL OF ROOF LIGHT ON FLAT REBATED CURB

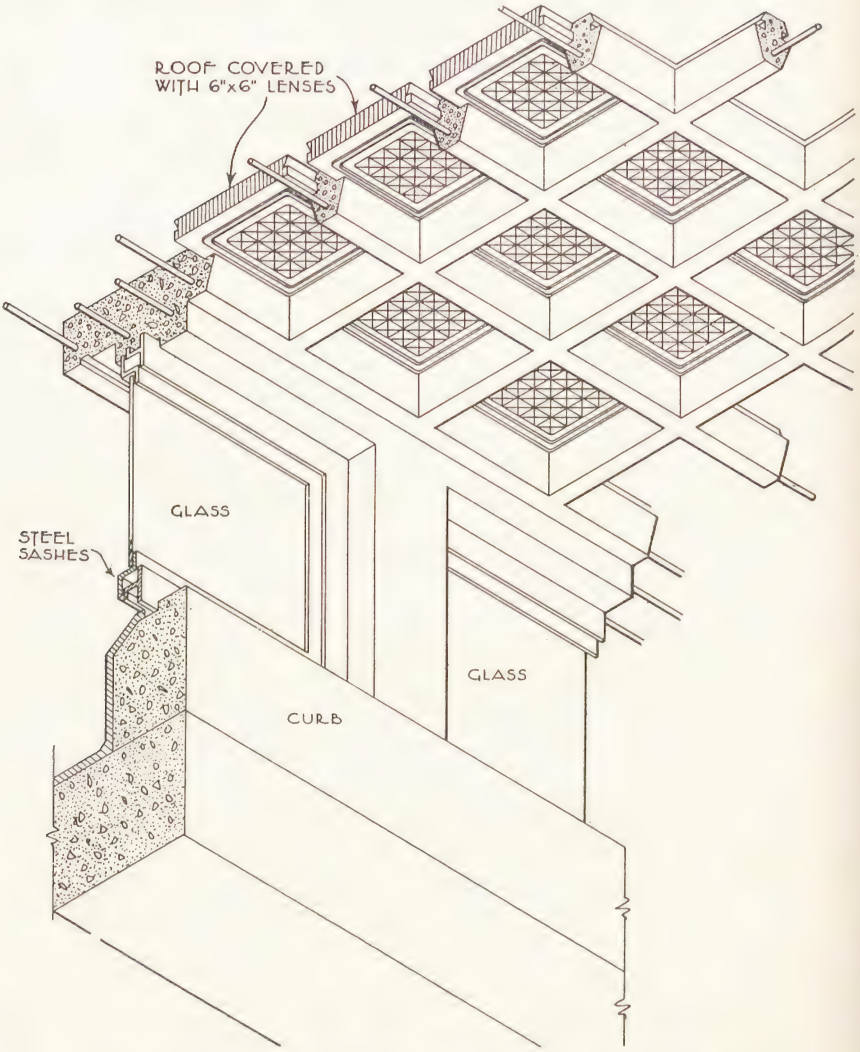


Fig. 17.—LANTERN LIGHT IN "GLASS-CRETE" ON RAISED CURB

the maintenance costs are negligible, and efficient heat- and sound-insulation and resistance to corrosion are provided.

The top surface of the concrete may be finished with asphalte flush with the lights.

Quarry tiles, stone slabs, or other finish may be adopted where the roof light is fixed on a flat rebated curb (see Fig. 16). Fig. 17 shows a lantern light on a raised curb in the same materials. The sides of the lantern are fitted with steel sashes, and the roof is constructed with 6-in. by 6-in.

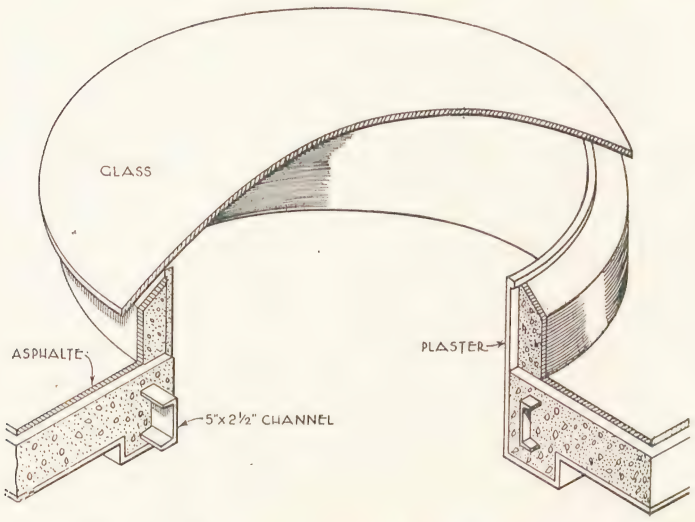


Fig. 18.—ISOMETRIC SKETCH OF GLASS DOME LIGHT

lenses. Fig. 18 shows a glass dome formed in one piece, and suitable for spans up to 6-ft. diameter. The dome is fixed to the curb by means of special fittings.

For further examples of glass work, the reader is referred to page 161, Vol. III.

Roof Insulation

Flat roofs generally require some form of insulation. Where the roof is of timber construction a certain amount of insulation in some cases is adequate by fixing a wall board to the ceiling. A more even distribution of temperature would be obtained if the insulating board were placed directly under the roof boarding or bitumen sheeting, and using a lath-and-plaster ceiling. When the insulating board is placed directly under the bitumen sheeting or asphalte, it

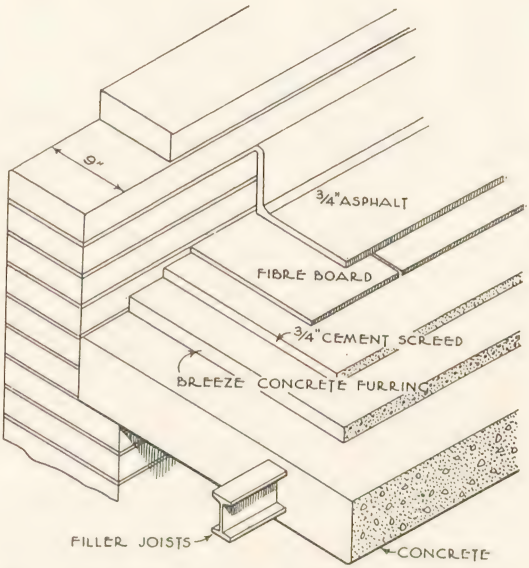


Fig. 19.—FLAT ROOF IN CONCRETE WITH ROOF INSULATION

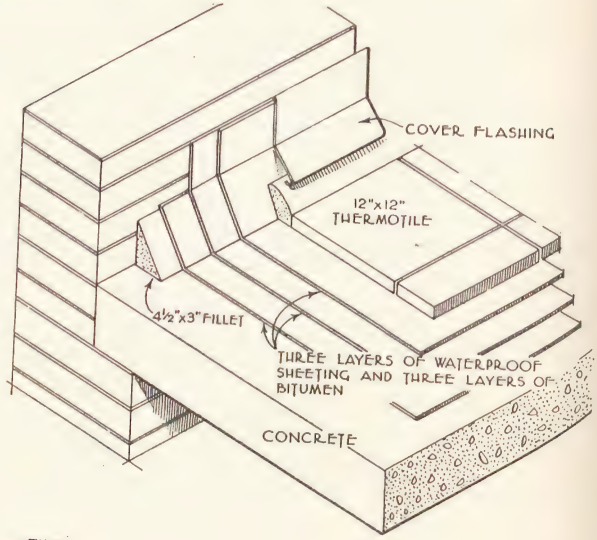


Fig. 20 (*right*).—FLAT ROOF INSULATION

Employing top cover of asbestos cement tiling, cemented to surface and to each other with bitumen.

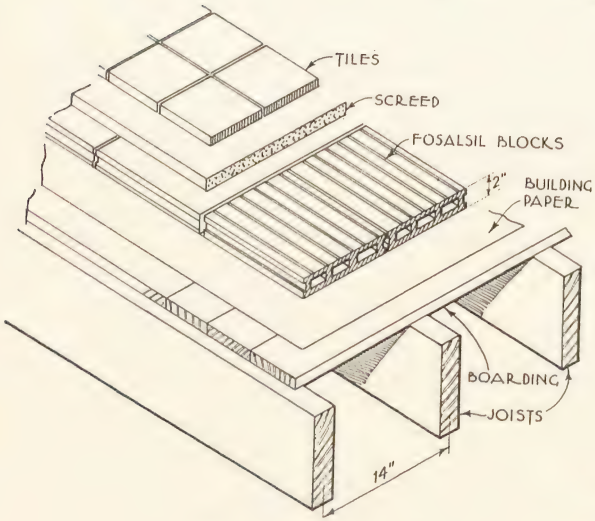


Fig. 21 (*left*).—ROOF INSULATION

Insulating blocks laid on building paper, the base being timber construction.

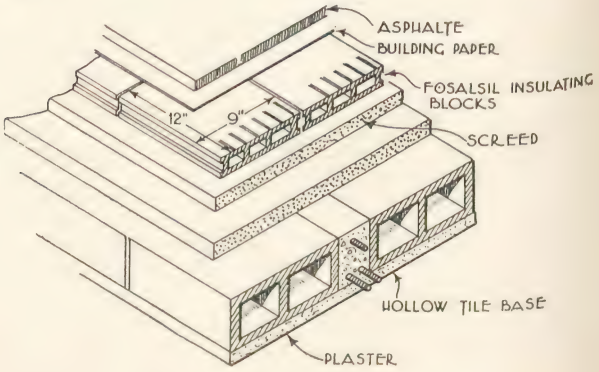


Fig. 22.—ROOF INSULATION

Insulating blocks on hollow-tile base. Methods shown in Figs. 21 and 22 give a high insulation value.

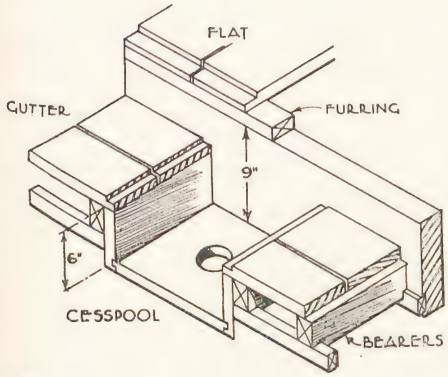


Fig. 23.—PARALLEL GUTTER TO FLAT ROOF

Showing detail of cesspool with joists parallel to gutter.

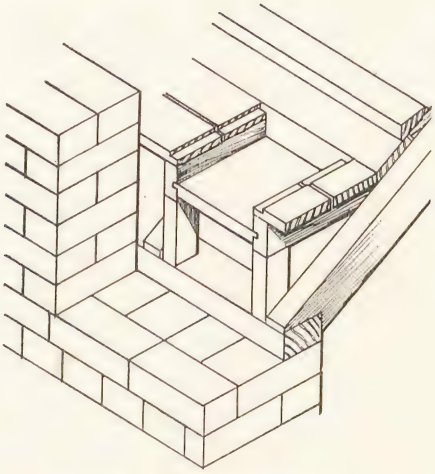


Fig. 24.—TAPERING GUTTER

Isometric sketch of chute to parapet gutter. Note bearers are nailed to side of rafters.

tends to raise the surface temperature during the summer (see Fig. 19). This can be overcome by using asbestos tiles. An excellent tile for this purpose is "Thermotile," which is made with a mixture of asbestos-cement waste. These tiles are laid on three layers of bitumen felt, cemented on to the roof surface and to each other with bitumen. The tiles measure 12 in. by 12 in. by 1 in., and weigh approximately 8 lb. per square foot (see Fig. 20). Fig. 21 shows insulation blocks laid on building paper, the base being in timber construction; and Fig. 22 shows the same blocks with a hollow-tile base. These latter types give a high insulation value.

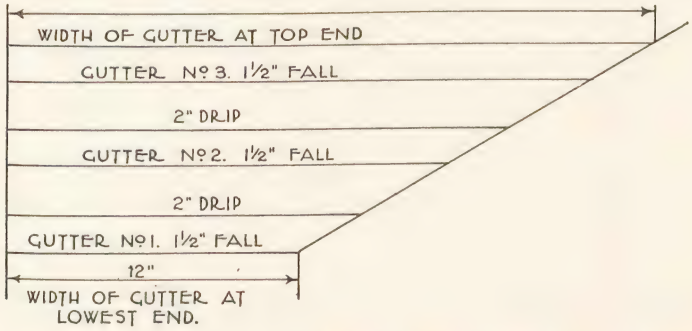


Fig. 25.—DIAGRAM SHOWING WIDTH AT TOP AND BOTTOM OF EACH GUTTER

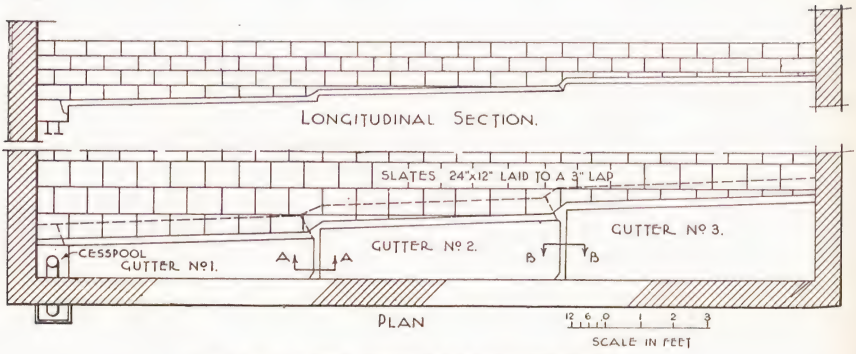


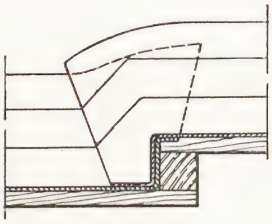
Fig. 26.—LEAD GUTTER TO PARAPET WALL

Preparation for Gutters

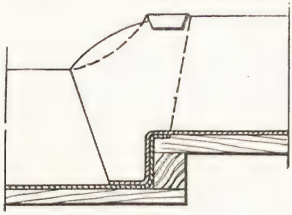
Gutters may be either parallel or tapering on plan.

Parallel Gutters

These are formed by fixing a pole-plate at a distance of from 9 in. to 12 in. from the wall. This pole-plate carries the lower ends of the rafters. Between the wall and the pole-plate short pieces of timber called bearers are fixed, to carry the gutter boarding. These bearers are fixed at 15-in. centres, and must be so fixed as to give the necessary fall and drips when



Section through drip A–A from wall side.



Section through drip showing finish of lead against wall.

Fig. 27

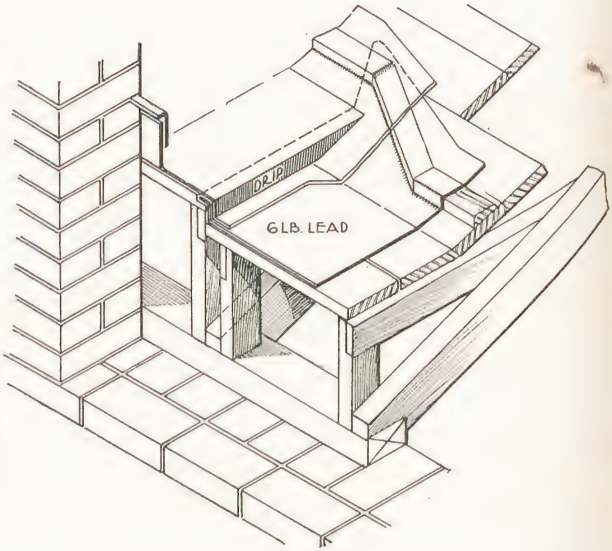


Fig. 28.—ISOMETRIC SKETCH OF A TAPERING GUTTER, SHOWING DRIP

Wall removed to show construction more clearly.

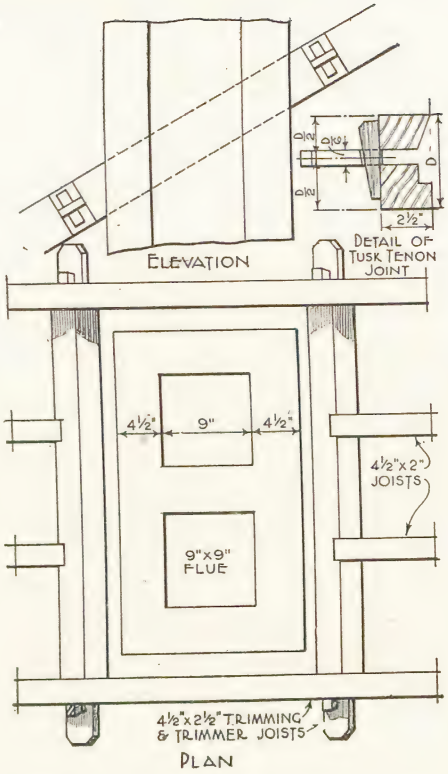


Fig. 29.—Trimming to chimney stack

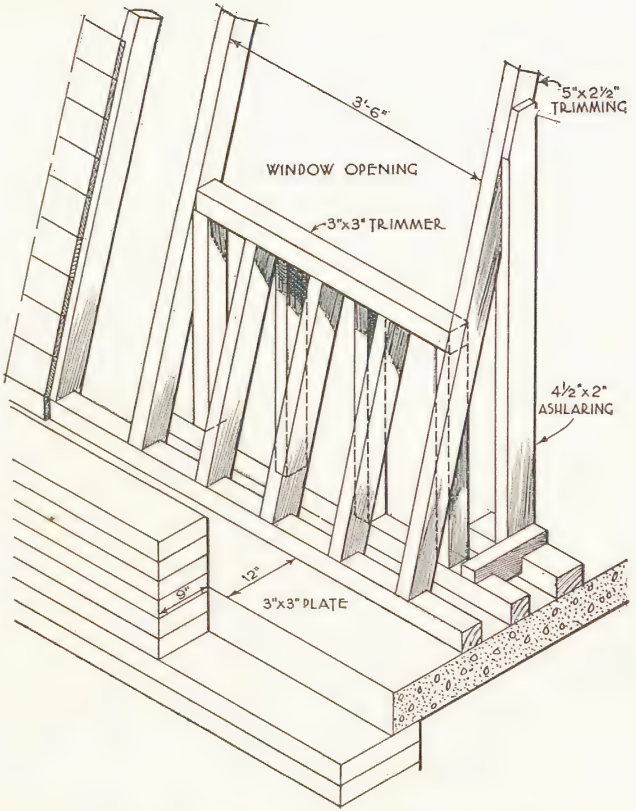


Fig. 30.—Trimming for dormer window

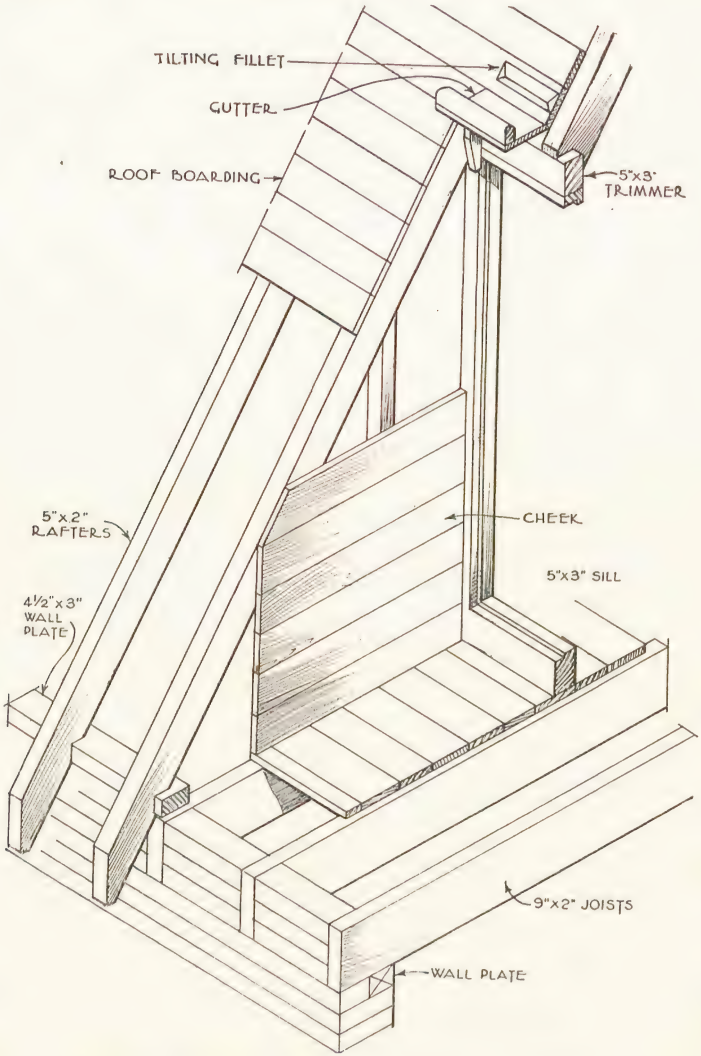


Fig. 31.—TRIMMING FOR INTERNAL DORMER

the boards are laid. Fig. 23 shows part of a parallel gutter to a flat roof, together with the construction of the cesspool.

Tapering Gutters

These differ from parallel gutters in being formed on the top of the rafters, so that as the gutter rises from the outlet its width increases. The bearers in these cases are nailed to the side of rafters (see Fig. 24). Fig. 25 shows the method of setting out, and Fig. 26 plan and

section of a complete gutter. Fig. 27 shows sections through a drip, one from the wall side and the other from the roof side, and an isometric sketch of the drip is shown in Fig. 28, the wall being removed to show the construction more clearly.

Chute

In some cases, instead of discharging the rain-water into a cesspool, it is taken, through an opening formed in the wall by means of a chute, direct into a rain-water head. The construction is shown in Fig. 26.

TRIMMING

Chimneys, etc.

Where chimneys, dormer windows, skylights, or other openings occur in a roof, it is generally necessary to trim the rafters in order to leave sufficient open space. The trimmers are tenoned into the trimming rafters, and these are generally made $\frac{1}{2}$ in. thicker than the ordinary rafters. The trimmed rafters are notched to the trimmers. A frame is thus provided in the roof surface without any rafters crossing it (see Fig. 29).

Dormer Windows

The trimming for a dormer window is shown in Fig. 30.

Owing to building laws the projection of dormers is in some cases not permitted, so resort is made to what is termed *internal dormer*, and in place of a window a door opening is provided (see Fig. 31).

STAIRCASES

A STAIRCASE may vary from an imposing affair of steps in a public building, wide and easy to climb, to the narrow and steep staircase of a small cottage, and between these two extremes there is a vast number of different types.

It is a very curious fact that, in cases of demolition, a builder can often re-use doors, windows, and other fittings, yet however sound and good it may be, it is a rare occurrence for him to be able to re-use a staircase. Either it is lacking an inch or two in height, or it is slightly too high, too wide, or there is not room in the new building to fix it suitably. It may be taken as an axiom that if it is a building of an individual character, that is, almost any building other than a municipal housing scheme or speculative building scheme, the staircase must be specially made.

Proportions of Rise and Tread

The comfort of a staircase depends on the height and width of the steps. This, of course, is a very trite observation, but it may be taken as a general rule that the steeper the rise the narrower the tread. There is no definite rule as to the respective proportions, but a good guide is to state that going $\times$ rise $= 63$ in. Thus a 12-in.-wide step will give a $5\frac{1}{4}$-in. rise. Another rule is that twice the height + width $= 23$ or 24 in. In the case of a 12-in. by $5\frac{1}{4}$-in. step these two rules nearly coincide. Of the two rules, the second is the more consistent.

Landings

A staircase is always easier if constructed in two flights rather than in one. Its appearance also is improved when broken by the landing (Fig. 1A). The latter may be a " half-space," that is, where a complete right-about-turn is necessary, or a " quarter-space," which requires only a right or left turn. Many corporations have by-laws applying to public buildings, factories, etc., which will not allow more than twelve steps to a flight, and also by-laws which insist on a minimum width of the stair, say 4 ft. in a public building, or 2 ft. 6 in. in domestic work. The maximum rise allowed is usually 8 in., and the minimum width of tread 9 in.

Another point might here be mentioned. Where a half-space landing is constructed in two parts, as in Fig. 2, the single step is likely to be unnoticed and lead to accidents. If possible, three steps should be made, but at least two.

Fig. 1.—PANELLED BALUSTRADE

All woodwork natural colour. Note veneered walls. (*Architect: Douglas Wells, M.A., F.R.I.B.A., R.B.A.*)

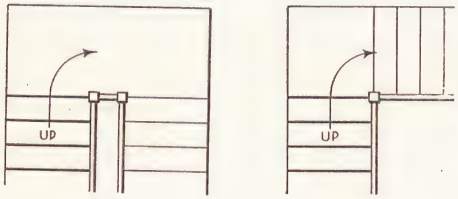


Fig. 1A.—HALF- AND QUARTER-SPACE LANDINGS

The ideal staircase should be well lighted, be of a generous width, always have a landing, and the rise easy, not more than 7 in. Unfortunately, owing to lack of available space these admirable rules cannot always be followed.

Use of Winders

Instead of a convenient landing, "winders" or triangular steps are introduced. This gives three steps taking the space occupied by a quarter-space landing. If "winders" are absolutely essential, there should be three, as they are really less inconvenient than two, the width of the tread in the centre being nearer the width of the ordinary straight step. Also "winders" are better at the bottom of a stair rather than at the top, as if an accident occurs it is less likely to be serious.

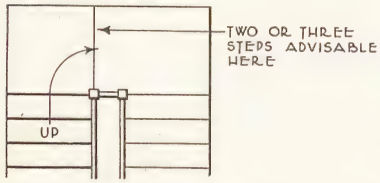


Fig. 2.—HALF-SPACE LANDING IN TWO PARTS

Headroom

Another important matter is the question of headroom, that is, the space allowed for a person to go up or down the stairs without being liable to catch his or her head on the ceiling above. Six ft. 6 in. should be the minimum for headroom.

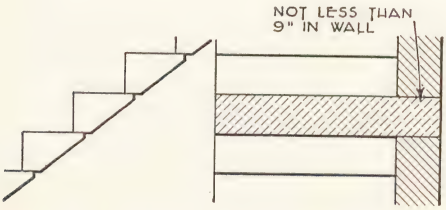


Fig. 3.—HANGING OR CANTILEVER STEPS

Materials Used

A stair may be constructed of stone (which term may include concrete, marble, or similar material), wood—the most common, and iron, the latter being principally employed for emergency or fire-escape staircases.

Stone and Concrete Staircases

The construction of a stone staircase is often very simple. If there is no particular decoration or moulding it may consist merely of solid blocks of stone, resting on a wall each side. In many buildings the staircase is formed of what are termed "hanging" steps, that is, resting on the wall on one side only. In such cases the steps must have at least 9-in. bed in the wall, and a few courses above and below built in cement. Tempor-

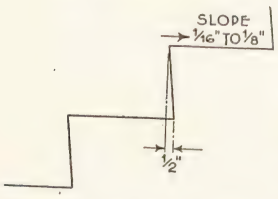


Fig. 4.—SLOPE OF STEPS

Fig. 4A.—CIRCULAR DOMESTIC STAIRCASE

Construction: reinforced-concrete treads and risers faced in Australian oak. Balustrade, "Staybrite" steel, with handrail of metal covered with "Doverite." Carpet specially woven to circular shape. (*Architects: Archibald & Archibald, F/A.R.I.B.A.*)

Fig. 4B.—A UNIVERSITY STAIRCASE

The main stairway from the first-floor landing in the extensions to the Students' Union premises, Liverpool University. (*Architects: C. H. Reilly, L. B. Budden, J. E. Marshall.*)

arily, the steps must be supported on the outer side by a rough wall until the brickwork is set and there is sufficient weight on a step end to hold it, when the temporary wall may be removed. It is quite plain that each step is a cantilever (Fig. 3), though it will be observed each step obtains some assistance from the step below. Theoretically, every tread ought to have a slight—very slight—slope inwards, from $\frac{1}{16}$ in. to $\frac{1}{8}$ in., and if the space be very cramped a little extra width to the tread can be gained by the riser sloping about $\frac{1}{2}$ in. inwards (Fig. 4).

Concrete or artificial-stone steps are usually made "non-slip" with a carborundum or similar finish, and again a little extra width can be given to the tread by a projecting nosing. This remark also applies to natural stone.

Circular Turret Stairs

Most of us have, at one time or another, climbed the circular stairs in a cathedral tower or the turret of a castle, but we may not have observed the ingenious way in which the steps are constructed to support themselves. Fig. 5 gives a sketch of a step, and shows how the centre post or newel is made by the steps themselves.

Fig. 4C.—A MODERN CIRCULAR STAIRCASE

House at Copt Heath, Warwickshire, the circular feature of which forms the entrance and wall and window of the staircase. An exterior view is shown on page 406, Vol. III. Here we see bottom of staircase with its wrought-iron balustrade, entrance door (which is protected by a porch), and circular window behind left column. Picture on next page shows top of staircase. (*Architect: Baron C. S. Underhill, F.R.I.B.A.*)

Concrete steps are occasionally made with a decoration formed by one or two lines of black or colour being " inlaid " in the tread, and if these are raised the merest fraction of an inch they add to its non-slip properties (Fig. 6).

Spandrel Steps

Spandrel steps, that is, splayed on the under side to follow the general slope of the stair, are invariably employed in buildings of any importance. They are desirable on account of appearance, and, besides which, give more headroom.

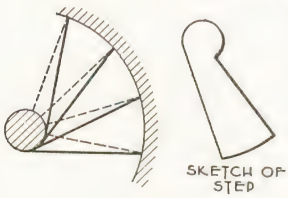


Fig. 5.—TURRET STAIR

Wood Staircases in Domestic Work

The usual construction of wood staircases in domestic work is two substantial raking pieces

Fig. 4D.—A MODERN CIRCULAR STAIRCASE

House at Copt Heath, Warwickshire. Top of the staircase. Bottom shown in the previous illustration. (*Architect : Baron C. S. Underhill, F.R.I.B.A.*)

or strings, with strong newel posts at the landings. The treads and risers are "housed" or let into the strings about $\frac{3}{8}$ in. to $\frac{1}{2}$ in., and wedged. The treads should not be less than $1\frac{1}{4}$ in. thick, and the risers 1 in. If the stairway be wider than 3 ft. 6 in., the steps should be supported by a rough centre string or carriage to prevent sagging. The remarks already made as to slope on tread and riser apply equally in the case of a wooden stair.

A hardwood stair is always to be desired, but it is well to point out that it is apt to become slippery. One method of obviating this is to employ a rubber strip on the edge of the tread.

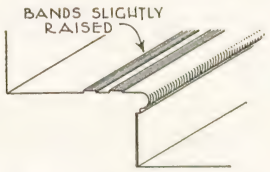


Fig. 6.—DECORATED TREAD

Some Notes on Landings

In the case of a quarter-space landing, unless the newel post can be carried down to the floor (which is not always possible), the whole of the landing is practically a cantilever,

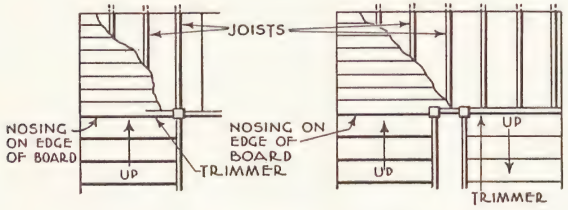


Fig. 7.—CONSTRUCTION OF LANDINGS

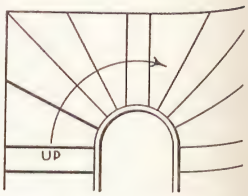


Fig. 8.—WREATHED STRING

though the newel, with the string acting as a strut, certainly gives some support.

Fig. 7 shows the construction of both quarter- and half-space landings, and it should be noticed that the boards should run parallel with the lower flight of steps, as in this case the nosing is on the floor itself, not a separate piece to be let in.

In cases of winding steps a good deal of labour is entailed in the notching of the newel posts.

Use of the Wreathed String

The construction ought to be carefully studied where newel posts are dispensed with and the string itself is curved. This is known as a wreathed string, and is usually formed by about four thicknesses of $\frac{3}{8}$-in. timbers, steamed, bent, and glued together in short lengths overlapping each other.

It will be noticed in Fig. 8 that the narrow width of the winder at the point where it is housed into the string means that the latter must suddenly alter its rake and at the same time take a sharp bend. We shall mention this point again when we come to the matter of the handrail.

Cut String

We stated above that the steps were housed into the strings, but occasionally a cut string is used, with the nosing of the tread returned (Fig. 9). It might be noted that to avoid labour in rounding the nosing of the tread across the grain of the wood, a separate piece should be let in at the end of the step, and very often a shaped piece termed a bracket is sprigged on to the string. This is a common feature in eighteenth-century woodwork. Note in the section, how, by the method of mitring, the

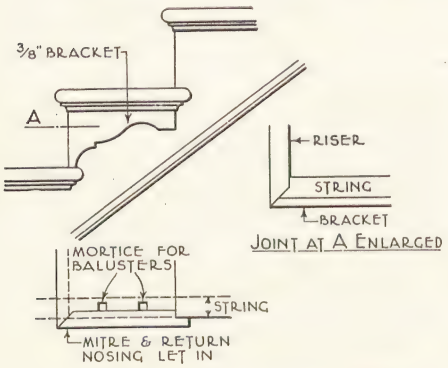


Fig. 9.—CUT STRING

end grain of the bracket does not appear.

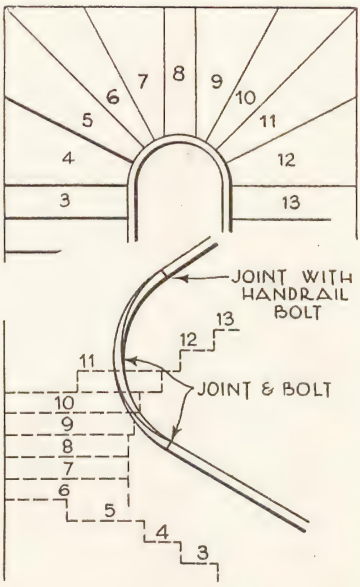


Fig. 10.—WREATHED HANDRAIL

The Balustrade

A very important matter in connection with a staircase is the balustrade and handrail. The first point to notice is the height of this necessary protection. For domestic work a height of 2 ft. 8 in. to 2 ft. 10 in. vertically direct from the riser is advisable, with 3 ft. or an inch or two more on the landings. In public buildings the balustrade should be a little higher.

The newels, balusters, etc., may be plain or square, pierced or turned, or whatever is desired, but especially in domestic work there should never be more than a 5-in. clear space between them. With the ordinary raking string the balusters are nailed to it, but with the cut string above mentioned they should be tenoned into the step.

The Handrail

We might here point out the difficulty of the wreathed handrail with the winding stair. In Fig. 10 the slope automatically becomes very steep owing to the narrowness of the treads, and we would also emphasise the danger in a case of this kind. Take the instance of a person coming down, standing on step No. 11. The handrail is normal height, say 2 ft. 8 in., yet immediately in front, and quite close, it has dropped 14 in., and he or she is apt to feel somewhat unsafe. The writer has observed a case in a public restaurant where this occurs, and to keep customers from getting too close to the handrail a piece of board with a large plant on it has been arranged.

In all these cases the handrail is far too heavy to be bent in a manner similar to the string. It must be worked out of the solid, as

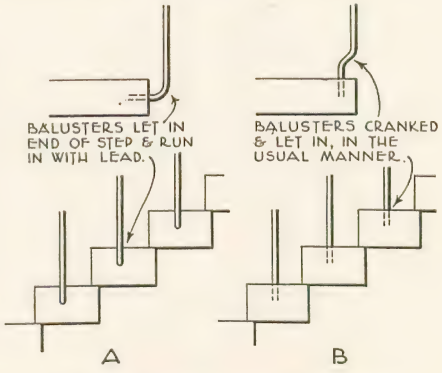


Fig. 11.—ALTERNATIVE METHODS OF GAINING WIDTH

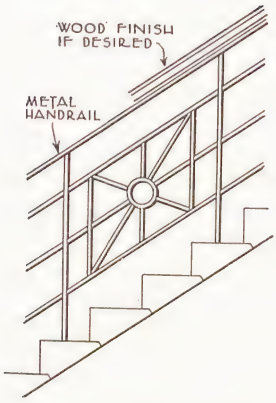


Fig. 12.—DECORATIVE PANEL

a mason works a block of stone, though in the position mentioned the wreath would have to be in two pieces (see Fig. 10) and secured to the straight lengths by handrail bolts. A few other cases also require special working, as the ramp, where the handrail must suddenly jump to a higher level, a quadrant corner, or indeed any curved work.

The modern custom is to eliminate the old-fashioned open balusters, and to have the balustrade panelled solid from string to handrail.

In the case where the staircase is between two walls there should undoubtedly be a wall handrail on one side, the right hand going up preferred. A wall handrail may be nothing more than a pole fixed to brackets at intervals, the brackets in their turn plugged to the wall.

Instead of the handrail crudely finishing into a plastered wall in the case of wooden stairs, it may be received by a wood patera, and a lath should always be nailed on the under side to cover the joint between the string and the plaster soffit.

Iron or Bronze Balustrade

In the case of a stone or concrete stair, the balustrade is invariably of iron, the balusters themselves being let into the steps and run with lead.

They are tenoned through a ribbon rail or may be welded on to it. The ribbon rail may itself act as handrail, or a wooden handrail can be screwed to it.

In high-class work bronze is occasionally used for the balustrade.

If the width of a stair is specified as 3 ft., it does not follow that the whole of the 3 ft. is available for walking space, as a little is lost by the balustrade. In the case of stone stairs, Fig. 11 shows alternative methods of trying to gain a little more width by a different manner of fixing the balustrade. In A, decidedly more width is obtained, but the balusters do not appear to be as securely fixed. In B no more walking space is allowed, but greater width is obtained at the handrail level.

In many cases where the iron balustrade is utilised, it is designed more in the fashion of an iron railing, that is, only every third step carries a baluster or standard, and the spaces between are filled in with decorative panels (Fig. 12).

Iron Spiral Staircase

An iron spiral staircase can justifiably be employed in a cramped space where a really good staircase cannot be planned. In many cases

Fig. 13.—EMERGENCY IRON STAIRCASE FOR FIVE-STOREY FACTORY
Note method of avoiding pipes and door openings.

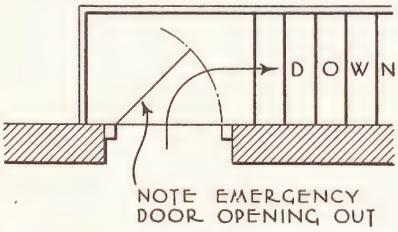


Fig. 14.—Door opens on to landing of emergency staircase

these staircases are only 3-ft. 6-in. to 4-ft. diameter, and the rise is of necessity extremely steep.

Emergency Iron Staircases

Iron staircases are often seen outside large buildings, such as hotels and factories, to be used as emergency staircases in case of fire. The emergency door should not open directly on to the steps, but always on to a landing, and it is better still if the stairs are parallel with the building, as Fig. 14, not at right angles, as there is thus less likelihood of an accident occurring in case of panic. There should be not more than twelve steps without a landing.

It is often far from simple to plan an emergency staircase to serve the various floors and yet not interfere with traffic. The photograph (Fig. 13) shows a staircase designed by the writer to serve a five-storey factory. It might be observed that it was most difficult to plan the lower flights to avoid the various large pipes leading to and from the engine house, and also to keep clear of the door openings on the ground floor.

The construction of this type of staircase usually consists of a string formed of an iron plate about 9 in. by $\frac{3}{8}$ in. The treads, generally open gratings, are bolted to it (see Fig. 15). The balusters are also bolted direct to the string. In this class of staircase, the risers are nearly always omitted entirely, which gives a little "toe-room" and thus makes the space occupied by the flight a little shorter. The landings are as a rule iron gratings supported upon light girders, and the raking struts resting upon the walls are shown in the photograph.

It is needless to say that an emergency staircase should always deliver into an open yard or a public street.

Any staircase which appears to be in the slightest degree inconvenient should be studied in order to see if these small inconveniences could have been eliminated, though in many cases, owing to cramped space, an ideal staircase is impossible.

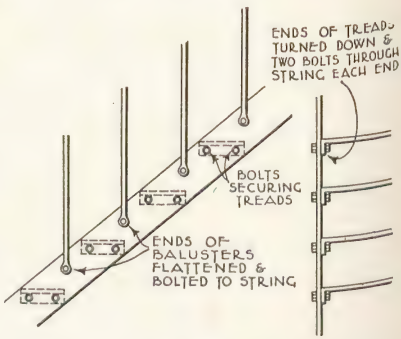


Fig. 15.—Emergency staircase—construction

SMALL TOOLS FOR THE BUILDER

THE introduction of portable tools for the cutting, drilling, and breaking which form so large a part of the builder's work has opened up a large field for the inventor. The inevitable result is that many devices are put on the market whilst in an incomplete form, the improvements being made in course of time as a result of the users' complaints. In other words, the user stands the expense of experiments.

This expense can be largely avoided by exercising care in purchasing, by buying only from established firms, by demanding a thorough demonstration, and by asking for the names of other users, some of whom will be well enough known to the inquirer to be approachable for opinions as to the merits of the tool.

Electrically-driven Tools

The first problem is to decide whether to use pneumatic or electrically driven tools. We will suppose that the reader is intending to buy one or more electrical tools, the use of which bringing with them the question of current supply. Although many jobs are or can readily be connected with the local mains, the charges for current are apt to be high, whilst the installation of a meter, with the fuse boxes, switches, and cables, by competent electricians runs into a great deal of money.

The next difficulty is that though the Grid system is making rapid headway, it is not yet universal, so that with most electric tools being fitted with motors to run at between 200 and 240 volts, there is always the possibility of being faced with a direct low-voltage supply of current, which is, of course, not capable of being transformed to a higher voltage as is an alternating supply.

In London alone there are nearly a dozen different voltages in use, so that added to the risk of some jobs having no current available, it is as well to commence by purchasing a small generator or, if cost is a consideration, having one made up in one's own workshop.

Electric Generator Sets

With ready-built machines portability is the first consideration, and many types are available at prices ranging from fifty to one hundred pounds.

As is the case with the home-made outfit it is necessary to calculate

what size will be required, and for this purpose recourse must be had to the catalogue of the tool or tools to be used.

As an example, suppose two hammers are to be run with six 60-watt electric lamps. The hammers are described as taking 4 amperes each at 220 volts. Multiplying volts by amps. we get watts, in this case 880 for one hammer, or 1,760 for the two. Six lamps at 60 watts will take another 360, giving a grand total of 2,120 watts.

Dividing by 746, the number of watts in a horse-power, we find we want around 3 horse-power, or if we want the electrical power we divide by 1,000 to get the kilowatts demand. Ready-built sets of engine and generator are usually described as having an output of so many kilowatts, so that in this case, allowing a small margin, to be on the safe side, we should buy a 3-kilowatt outfit.

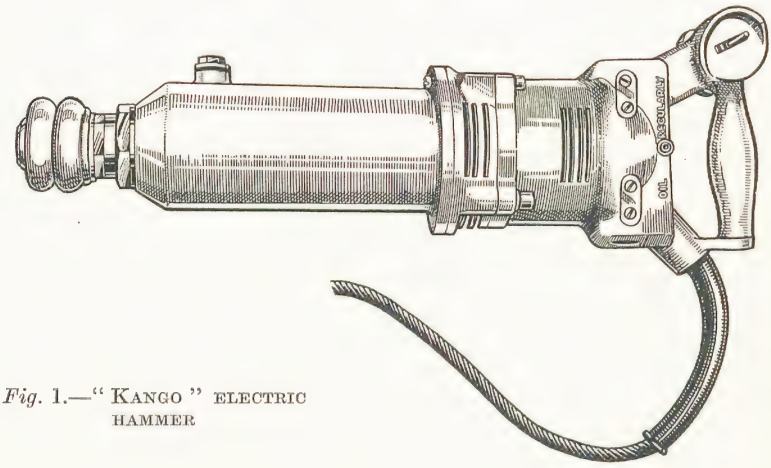


Fig. 1.—"KANGO" ELECTRIC HAMMER

Assembling Generator Set

In assembling a set, as most builders have on hand a variety of engines as used for hoists, crushers, etc., a little care is necessary to get good results. Although all electric tools have universal motors, that is, ones which will run equally well on alternating current or on direct, it is not advisable to purchase an alternating-current generator however tempting the price. A 2-kilowatt generator can be had for as little as £5, but unless the engine runs at a perfectly regular speed, that is, without fluctuating more than, say, 3 per cent., the current will not be produced at an even frequency, with the result that the power output will be extremely variable. The only safe choice is a small high-speed direct-current dynamo, guaranteed by the supplier to be self-exciting. If it is not good in this respect it may fail to give any current at all when started up.

Speed of Running

The next point concerns the speed at which it runs. This will probably be in the nature of 1,200 revolutions a minute. If, for example, an engine of 5 horse-power is to be used, and it runs at perhaps 700 r.p.m., it will be necessary to gear the engine up to the dynamo. This means that we can expect only half the horse-power at the other end of the belt, so that instead of 5 by 746 watts output we shall get seven-twelfths of 3,730 watts or 2,177 watts. In this case the engine will be powerful enough, but had we chosen a 3-horse-power engine running at 770 it would not do the job.

Belt Drive

The connection between engine and dynamo can be best made by means of one of the new endless V-belts which need not be run tight to get a drive, even if the engine and dynamo are set close together.

Completing the Generator Set

A double-pole switch, a double fuse board, and, if desired, a cheap voltmeter will complete the set, which can be mounted on a channel-steel frame with or without wheels.

Maintenance of Plant

The likeliest place for trouble on such a set is the commutator and brush gear. The former becomes blackened after considerable use, but can be cleaned by holding 00 glasspaper fitted to a curved piece of wood on to the commutator.

Dynamos are apt to and indeed must warm up when run for any length of time, but as long as the hand can be borne on the outside of the windings there is no need to shut down for a cool-off.

Regular lubrication of the dynamo shaft is of course essential, and from time to time the whole machine should be freed from dust, which is apt to collect in odd corners such as between the segments of the commutator.

Should the commutator become grooved or pitted it is not a difficult matter to remove it, when it can be trued in a lathe.

These remarks apply equally to the armatures of all motor-driven tools, neglect being soon apparent by reason of the heavy sparking at the brushes.

PRECAUTIONS TO BE TAKEN WITH ELECTRIC TOOLS

Although the average small tool running at 200 to 240 volts takes only around 5 amperes even under full load, operators can receive dangerous if not fatal shocks unless care is taken to install a suitable earth return from every machine.

In most cases electric tools are supplied with three-core cables

containing one red, one white, and one black inner lead, the red being the earth, but, the leads being necessarily short, extensions are nearly always fitted by the workmen, and the earth omitted, particularly when connecting to an electric-light socket.

The safe rule is to fit a three-pin plug on the end of every tool lead, and to have corresponding sockets fitted to other lengths of three-core cable, the final electric lamp-plug having the black and white connected and the red brought out for connection to a convenient water pipe or stanchion.

When two or more machines are in use, hanging multi-point connectors can be installed by an electrician, so that connection can be made by the mere insertion of the tool lead-plug.

A Suitable Warning Notice

The writer has the following notice affixed to the carrying boxes of all electric tools, and has so far had no accidents :—

WARNING. THIS MEANS YOU

Electricity like water can escape through a leak. You can give it an easier path than through your body by providing a wire through which it can run to earth. Do not start this machine until you have made sure you are using a three-pin plug on a properly earthed three-pin socket. Ask the foreman to find out for you if you can't find out yourself. If there is no three-pin socket run an earth wire from the machine to the nearest water pipe, iron railing, or stanchion.

In the event of a man getting a shock, cover the burns with lint and lay him down in a quiet place covered with a coat or rug. Do not give stimulants.

Wiring should be done with elephant cable in which the leads are enclosed in a flat-section rubber covering, using the size known as 7/036 or 7/044 if it is twin, or 3/036 if it is triple. The latter is strongly advised.

All tool leads should be hung on hooks in the wall, but if this is not possible a protecting run of timber should be laid for the passage of wheelbarrows. There have been several fatalities through neglect of this precaution, owing to cutting of the rubber covering by the iron wheel.

DRILLING AND CUTTING TOOLS

Drilling

The simplest tool for the drilling of large quantities of holes in brick walls is the hand-operated spring hammer, in which rotation of two handles alternately lifts and releases a hammer against the action of a spring. The bits are hollow to allow of escape of the core, and suffer

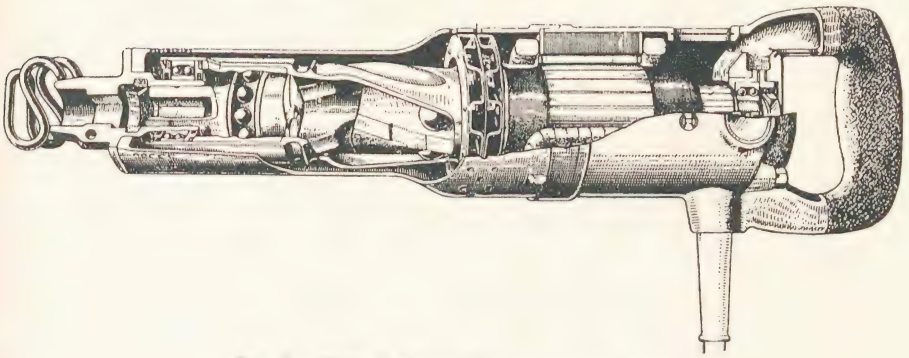


Fig. 2.—THE "BOSCH" ELECTRIC HAMMER

from only one disadvantage, which is their length. This hammer must not be confused with the small one used for Rawlplugging, as it costs around £7, and is naturally larger and capable of heavier work.

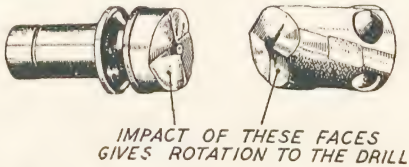


Fig. 3.—STRIKER PARTS OF "BOSCH" HAMMER

It will drill a 1-in. hole with 6-in. penetration in stock bricks in half a minute, or with smaller drills at correspondingly greater speeds.

Cutting of door openings in brick can also be speeded up with this tool by drilling a row of holes at the desired line, leaving the bulk to be cut with hand chisels.

Until recently there were no small tools capable of cutting and drilling except such as were driven by compressed air, which, although a convenient and economical method, suffers from a cost complex due to the natural association of it with the devastating road breaker or pom-pom.

As will be seen in this article, this difficulty has been overcome, and many builders will prefer to make use of electrically operated tools, as the first cost is so much lower.

The Electric Percussion Hammer

The essential feature of electric percussion tools being rapidity of the blows, the most attractive design consists in a solenoid machine in which a coil of insulated wire forms a magnetic field, which attracts a jumper against the action of a spring. Unfortunately the windings in this design of tool become very heated, and the usual hammer contains a ruggedly built electric motor whose rotary motion is converted into a reciprocating one by some patented mechanism.

Fig. 2 shows a "Bosch" motor-type hammer. This operates through the medium of a striking-block carrying four large steel balls in recesses

in its outer cylindrical face. These balls, which protrude slightly from the recesses, engage with helical grooves cut in the recessed end of the armature shaft. As the latter rotates it throws the striker forward, causing it to impart a blow to an anvil piece, which in turn passes the blow to the end of the chisel or drill. To achieve turning of the drill so as to avoid jamming, the anvil is shaped as shown in the sketch, the impact of the two inclined faces giving a twist to the rotatable anvil. The rebound of the striker carries the balls back into the armature shaft grooves, and the action is repeated.

It is obvious that such a mechanism must be of high-grade steel, and that it must be regularly lubricated if excessive wear is to be avoided.

Operation and Maintenance of Percussion Hammer

The makers advocate regreasing every 100 hours, and it is not unfair to assume that a new anvil will be required every 400 hours. Wear on the impact faces can be much reduced by seeing that the hammer is kept pressed to its job so that the force of the blow between tool shoulder and hammer body inside the spring tool-holder clip is kept at a minimum.

So successful are these hammers that they are always overworked, being used on material which would daunt their larger brother the pom-pom. This results in blunted tools and reduced output.

It is advisable to purchase a duplicate set of tools, so that the delay can thus be reduced to a minimum, although the sharpening is done very quickly by the English agents.

Paying an extra penny an hour to the operator, the total running cost, including writing off first cost in two years, has worked out at 2*s.* an hour. If the user does his own regreasing and tool sharpening this figure will be reduced to 1*s.* 10*d.*, but even the higher figure is extremely small in comparison with the amount of work the hammer will do.

It must be borne in mind that every 400 hours' work may entail a spare-parts bill for six or seven pounds, but this figure can be lowered by careful handling, particularly by avoiding idling by the operator who is apt to put so little pressure on the tool that the major part of the blow is taken up by the mechanism instead of being absorbed at the cutting end.

There is another type of hammer, in which a different mechanism is adopted to convert the motor revolutions to blows, the makers claiming longer life to the parts ; whilst yet another is marketed which converts by the use of an intermediate air piston.

In buying a hammer it is as well to remember that rapidity of blow is the essential requirement, whilst demonstrations should be of as extended a nature as possible and on the actual material to be handled.

Performance

Channelling in brick should be done at about 3 ft. a minute, whilst the penetration in good-quality concrete should be about 4 in. a minute for a $1\frac{1}{8}$-in.-diameter hole.

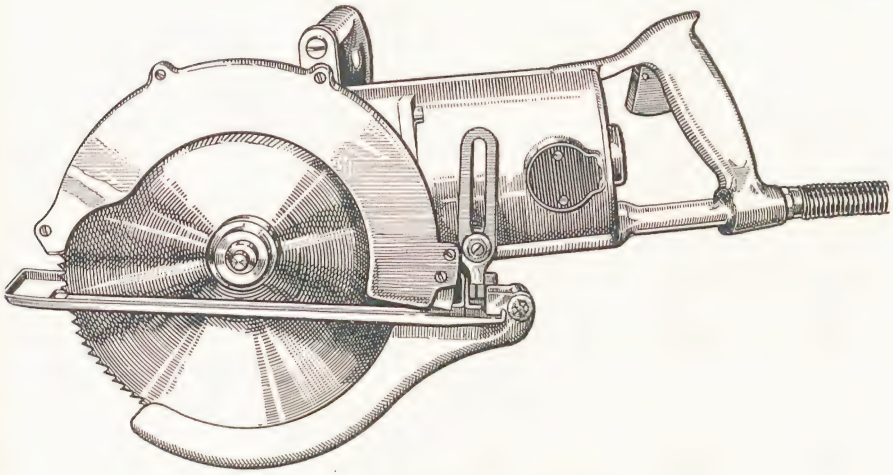


Fig. 4.—ELECTRIC SAW TOOL

The weakest point in electric hammers is the actual tool, which, being kept small so as to come within the capacity of the motor, is unable at present to show a long life. In purchasing, it is well to satisfy oneself that tool replacements can be readily obtained. The hammer being a percussion tool, there are times when the shattering effect is a disadvantage, and it is an advantage to use an ordinary electric drilling machine with a special bit.

Electric Drills

Drills can now be bought tipped with Wimet steel, which will handle the hardest materials, and for plugging in soft brick are preferable to any other method. Care is necessary so that the tip should not be stripped from its lower-grade body, and it must be remembered that the tips cannot be sharpened on ordinary wheels. With these qualifications they have everything to recommend them.

Cutting Tools

The introduction of steel-centred discs coated with a ring of aloxite carborundum or other abrasives has led to the use of electric-motor-driven machines for the shaping of bricks, tiles, and similar hard substances, the speed and accuracy of the work being many times greater than by hand, but a satisfactory substitute can be built from a grinder head belt-driven from a mixer engine.

A rough wood stand provides all that is needed, the high speed necessary being obtained by running the belt from the flywheel rim and not from the pulley of the engine.

For builders who require something more elaborate there is a wide

choice of electric drills, which can be fitted with discs or saws in any variety to suit material, whilst there is now available a choice of electric saws specially made for use in the hand, which allows them to be taken to the work.

The illustration shows an electric saw, the under-side guide being movable to any angle so that bevels of any angle can be repeated at will.

Operating Cutting Tools

When cutting vitreous material, it is necessary to avoid any side movement of the cutting disc, which is extremely brittle. An extemporised slide built of angle iron supported on a bench will allow the saw to be moved along in a straight line, whilst the brick or pipe being cut is held rigidly beneath it in a wood rest. Water should be supplied as a lubricant, and in the event of there being no pressure supply a tank set on a convenient staging a few feet above the machine will answer the purpose.

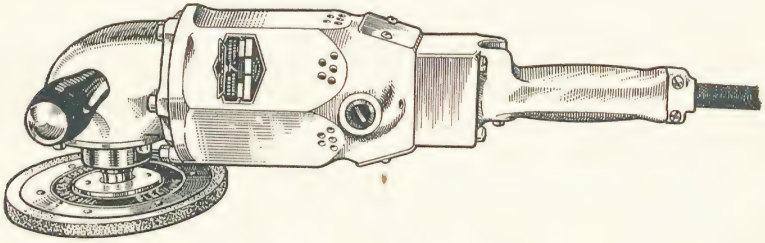


Fig. 5.—HAND ELECTRIC SURFACER

The cutting of timber within the limits of these electric saws presents no difficulties unless the saws be allowed to get blunt. If they are, the motor will become overheated or burnt out, necessitating a rewind, costing three or four pounds. Once again it pays to have two sets of saws, so that sharp ones are always to hand.

Made in various sizes, the most useful is one which will clean cut brick thickness, despite the extra weight involved and the slightly higher cost. Once again, there is no question of the enormous economies gained by their use.

Abrasive discs can be used for the cutting of steel reinforcing rods, but it is not an economical process over $\frac{3}{4}$-in. diameter, and up to that size a good bolt cropper is quite satisfactory and quicker.

Oxy-acetylene Metal Cutter

When it comes to cutting larger sections there is no doubt that the oxy-acetylene cutter is the best tool, particularly as it is of such frequent use in the cutting of steel sections. There are several makes of cutting-torches on the market, but there would seem to be little to gain from

buying except from the suppliers of the compressed gases, particularly as their servicing arrangements are country-wide.

A cutter taking up to 6-in. metal is large enough for most builders' purposes, and will enable quite heavy cast-iron sections to be blown away. The operator should be forced to use goggles, but the provision of gauntlets is apt to be a waste of money.

One warning. Under no circumstances should galvanised iron be cut with the flame. The fumes are definitely injurious.

Oxy-acetylene Cylinders

When ordering cylinders it is better to choose the small sizes, of 100 cu. ft., than the larger ones, which are too heavy to be easily moved. A sack barrow with rubber-tyred wheels can be easily adapted to carry an acetylene and an oxygen cylinder, and a tray or box fitted at the back for the holding of the torch and hose. Do not buy any torch which has internally tapered nozzles. The solid type can be filed back as it burns away, still presenting a smooth-sided annular opening, whilst the others are immediately rendered useless.

With a little practice the burner can be used for the cutting of bolt holes in erected steelwork. There is no basis for the idea that the heat reduces the tensile strength of the steel, as it is quite local in its effect.

GRINDING AND SURFACING

These operations can be carried out with discs faced with abrasives, and revolved direct on the spindle of a small electric motor or through the agency of a flexible shaft.

The former method has the advantage of lightness with a flexibility which allows of getting into awkward corners, but the latter allows of the use of a larger and therefore sturdier motor.

Flexible shafts unfortunately will not stand kinking, a misfortune which is only too apt to occur in building work, so a type should be chosen

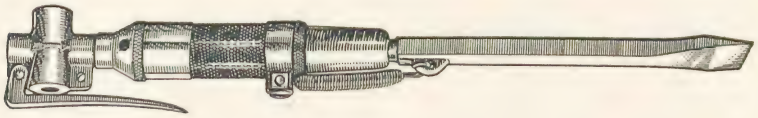


Fig. 6.—PNEUMATIC PAINT-SCALING TOOL

which has as strong an outer casing as possible. Frequent lubrication is essential, and the greatest care must be taken to avoid the inner cable getting wet. Considerable friction is developed between this inner cable, which is in form a spiral of piano-steel wires, and the outer case, with

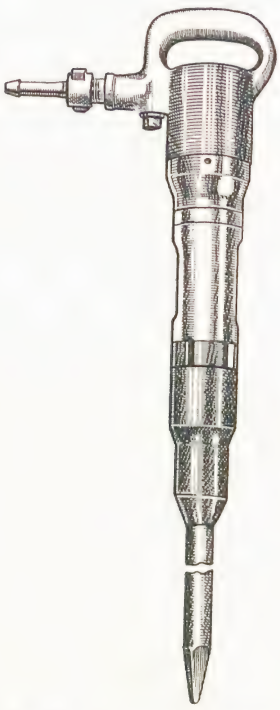


Fig. 7.—PNEUMATIC LIGHT CONCRETE BREAKER

the result that neglect causes the wires to become heated, to lose their temper, and finally to unravel.

Another cause of disappointment can be the excessive wear of the discs, which are not particularly cheap. This is mostly due to too much pressure, but frequently due to surfacing being confused with the actual cutting away of surplus material.

COMPRESSED-AIR TOOLS

There is a grave possibility that regulations will be made forbidding the use of electricity at voltages above 35 or 40, so that small tools of around 1 horse-power will have to be run at amperages of 40 or 50, which will lead in turn to such an increase in the size of supply cables and motors as to place electricity out of court for general building work.

Although compressed air is admittedly more expensive to produce, it has many advantages. The tools are rugged and little prone to wear or breakages; they can be operated by even less-skilled labour; air can be piped to any part of a job in low-priced barrel; there is no possibility of danger to the users; and finally, there is a far greater reserve of power for emergencies.

Compressors can be bought and mounted to a builder's own engine, or there is a wide choice of suitable sets, either Diesel-engined, with resultant economy in fuel costs, or petrol-engined for those with a prejudice in favour of the better-known mechanism.

All pipe lines from compressors should be fitted with a trap. The only care needed with the tools is to blow a charge of oil through them after a day's work.

Fig. 8.—SHEETING DRIVER DRIVEN BY COMPRESSED AIR

DOOR CONSTRUCTION

THE frame to which the door is hung usually consists of two jambs tenoned into the head, size about 4½ in. by 3 in., and rebated as required by the thickness of the door. Decay of the feet of the jambs can often be seen, especially in small property. This could have been checked if, when the building was erected, a base stone 3 in. deep, shaped to fit the door jamb, as in Fig. 1, had been used to lift the post above the wet and damp standing about the threshold, and which have usually been the cause of the decay.

With very large doors, sometimes a much heavier frame, either 7 in. by 3 in. or 9 in. by 3 in., is used. A very useful method to prevent this from moving by the banging of the door is to employ hoop iron, secured to the back of the frame, built into the wall, and turned up or down over a brick (Fig. 2).

The Batten Door

The simplest possible kind of door is what is commonly termed the "batten door." This consists of about half a dozen ¾-in. or 1-in. boards, nailed to three battens at the back. If the size is right it is then ready for hanging. Tee-hinges must always be used to a door of this type, as it is not thick enough for the ordinary butt hinges.

The Framed Door

The next class of door to be considered is the framed door. This may be specified as "framed and filled in" or "framed and panelled," but in any case the principle of the construction is the same. The main components of the framing are the two stiles, termed the hanging stile and the shutting stile, and the three rails, viz. top, bottom, and middle or lock rail. The three rails are tenoned through the two stiles, and wedged as shown in the skeleton of the door in Fig. 3. If the door be specified as "framed and filled in," the middle and bottom rails are usually only half the thickness of the stiles, so that the boards used for the filling will be flush with the stiles on the outside (see Fig. 4), and these boards are invariably grooved and tongued. To strengthen the door diagonal braces are occasionally used.

The framing of a panelled door is similar to that already shown in Fig. 3, except that all the rails will be full thickness. One or more muntins could be added, thus making a four- or six-panelled door, or more horizontal rails employed, in fact almost any number of

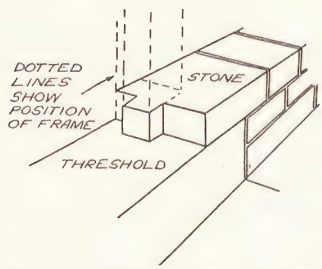


Fig. 1.—BASE STONE FOR FRAME ON WHICH DOOR IS HUNG

panels can be arranged. As is well known, the four-panelled door is most common, probably on account of its economy, as it means medium-sized panels, and the least possible amount of framing. Large panels are not advisable, as it is very difficult to obtain the material in one width, and however cleverly made the joints are apt to open.

Mass-produced Construction

Owing to the large number of doors required in municipal housing schemes, and by the energies of speculative builders, a number of firms provide the necessary quantity by mass production, but it should be noted that in most of these cases the rails are not tenoned through the stiles, but simply secured by hardwood dowels. If this construction be adopted more horizontal rails are desirable, as it is clear that three rails and a few wooden pegs are not a strong form. If properly done (Fig. 5) it is quite satisfactory, and there is one distinct advantage, that is, no tenons or wedges show through the stiles.

Standard Sizes

With regard to the subject of mass production, there are standard sizes for the various doors, and also standard thicknesses.

The standard sizes run as follows :—

7 ft. 0 in. by 3 ft. 0 in. 6 ft. 10 in. by 2 ft. 10 in. 6 ft. 8 in. by 2 ft. 8 in.
6 ft. 6 in. by 2 ft. 6 in. 6 ft. 4 in. by 2 ft. 4 in.

Thicknesses : 2 in., $1\frac{3}{4}$ in., $1\frac{1}{2}$ in.

Actually the doors are about $\frac{1}{8}$ in. less in thickness, this being accounted for by the loss in planing.

Special Designs or Sizes

As in everything else, if a special design or a special size be wanted it means an extra cost. Take, for example, the case of a circular or cambered head, as in Fig. 6. Though a camber of only $4\frac{1}{2}$ in. is shown it necessitates the top rail being cut out of a 9-in.-deep piece of timber instead of a $4\frac{1}{2}$-in. as usual, the surplus portion going to waste. Note also in the figure the additional labour of cutting the tenon and shaping the top of the stiles. If the head be semi-circular this is intensified, though in this case the top rail will be out of two pieces, jointed at the centre. Also it must be noted that the expense of the whole job is further increased because of a circular frame or casing, circular architrave, etc.

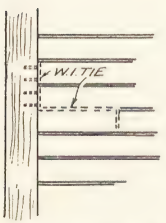



Fig. 2.—TIE FOR HEAVY FRAME

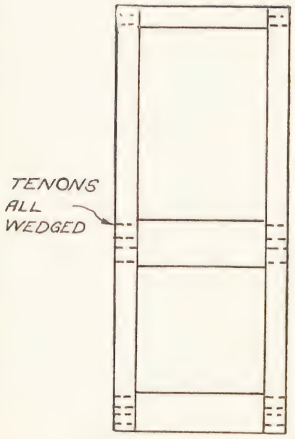


Fig. 3.—SKELETON OF FRAMED DOOR

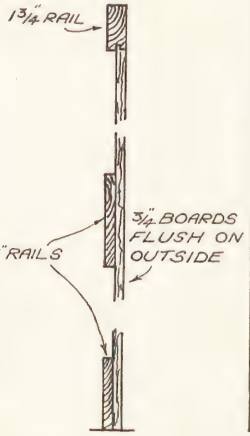


Fig. 4.—"FILLED-IN" FRAMED DOOR

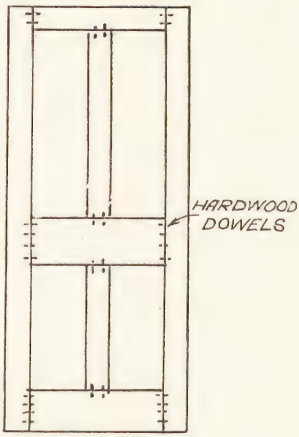


Fig. 5.—STANDARD DOOR WITH DOWELS USED INSTEAD OF TENONS

Use of Mouldings

It might be observed here that in a simple panelled door, with no mouldings whatever, no metal of any description is used in the construction. The panels are let into grooves in the stiles and rails, which allow them to shrink as the timber dries. This system, however, of a panel "square and flat" as the specifications say, is somewhat crude. Mouldings are usually desired, and if "stuck"—that is, the rails and stiles moulded on the solid—there is still no necessity for the use of nails. A certain amount more labour is entailed for the mitering of the mouldings.

Very commonly the mouldings are "planted" on the door, and in this case small sprigs are used. It should be pointed out that the mouldings should be sprigged to the framing, not to the panels, so as to leave the latter free to move. Fig. 7 shows stuck and planted mouldings.

Bolection Moulding

Another form of moulding often employed to give an imposing appearance to a door is the "bolection" moulding. This is a heavy moulding, which projects in front of the framing and is rebated to cover the joint between the rail and the panel. It is often used in conjunction with a raised panel (Fig. 8). The panel is an expensive matter, as in a first-class job it should be solid, which means a considerable amount of labour in working across the grain. In cheaper work the raised

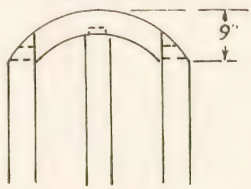


Fig. 6.—CAMBERED DOOR HEAD

Fig. 7.—STUCK AND PLANTED MOULDINGS

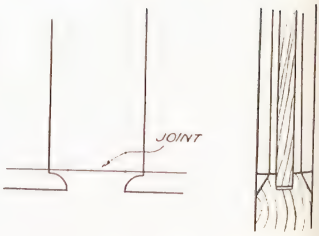


Fig. 9.—MASON'S MITRE

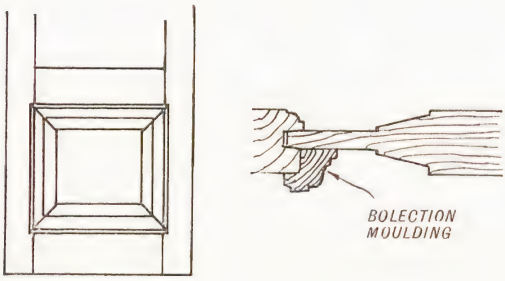


Fig. 8.—RAISED PANEL

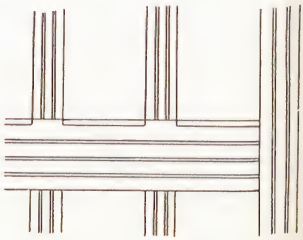
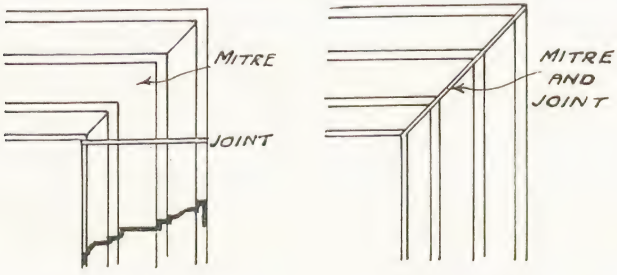


Fig. 11.—REEDING ON FRAMING

portion is simply planted on to a panel of ordinary thickness, and the bevel or "fielding" mitred around it.

The Mason's Mitre

In Gothic or ecclesiastical architecture, the number of panels is greatly increased, and fine specimens of doors may be seen in many churches, both ancient and modern. A very interesting point may be noted here. The most common form of moulding is the cove, but the point we desire to call attention to is the "mason's mitre." The top edge of the rails is invariably chamfered or bevelled, and the mouldings on the stiles "die" into this bevel. If Fig. 9 be referred to it will be observed that the bevel is not machined through the length of the rail, but "seats" are left on the upper edge, these seats for the moulding being worked across the grain. This entails a considerable amount more labour than the ordinary method.



Mason's mitre. Joiner's mitre.

Fig. 10—THE MASON'S MITRE AND JOINER'S MITRE

We might remark here that the difference between the

joiner's mitre and the mason's mitre is this: in the first case mitre and joint are one; in the latter the joint must be horizontal. Note the example in Fig. 10, showing the different methods in a wooden and a stone architrave. In all Gothic architecture, to be absolutely correct, mason's mitres should always be specified.

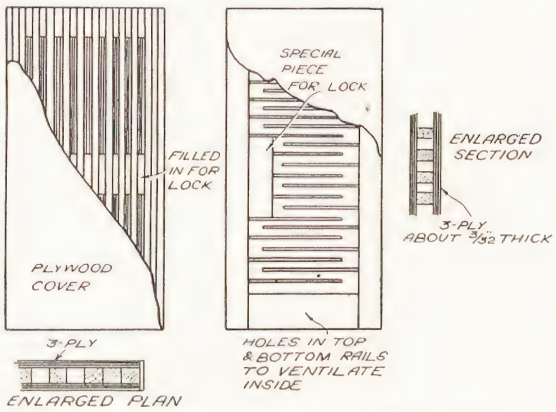


Fig. 12.—CONSTRUCTION OF FLUSH DOORS

In work of the Elizabethan and Jacobean periods, very often the stiles and rails themselves are moulded or reeded, but in these cases the mouldings of the stiles are "stopped" against the rails, not mitred (Fig. 11). The construction of many of these old doors, with their various forms of panels, is a study in itself. The same methods are still followed in all traditional work.

Glazed Doors

Glass is often employed in shop doors and upper panels in everyday work. It is not advisable to use the glass in large panels, as it is liable to break with the banging of the door. The glass should always be fixed with beads.

The Flush Door

A modern type of door in popular use to-day is the "flush" door. We show in Fig. 12 drawings of the skeleton of such doors in two different methods of construction. It might be noted that in the laminated doors no nails are used, the various ribs being simply glued and finally covered with two thicknesses of plywood. Both stiles may have edge strips to hide and secure the edges of the plywood faces. A variety of finishes can be obtained in the various timbers, but on account of the special piece of framing inserted to carry a mortice lock great care has to be taken in placing an order for these doors.

It is easily seen that if various types of finish for the same house are required, in order to match the furniture of the rooms, confusion may occur. The best method is to supply the makers with a plan of the building—showing how each door is hung (this, of course, is in order that the makers may differentiate between the hanging and the clapping stiles with regard to the clashing strip and the lock), and the finish marked (see Fig. 14). A reference should be attached as follows: O, oak. W, walnut. M, mahogany. CP, Columbian pine.

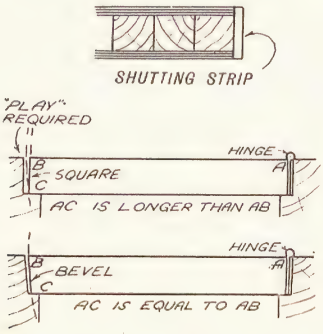


Fig. 13.—PLAY REQUIRED TO ALLOW DOOR TO SWING

Note thickness is shown exaggerated.

A further elaboration to this type of door may be added by the introduction of strips of inlay of another wood—ebony, perhaps —to form a panel or some form of design.

Another small point applies to all doors. It will be noticed in Fig. 13 (where the thickness is exaggerated), at the centre on which the door swings, the diagonal from A to C is slightly longer than the side of the door from A to B. This means that a certain amount of " play " must be given to allow the door to swing. This space can be reduced by a slight bevel on the outer edge, say about $\frac{1}{16}$ in., but this is done only in the best-class work.

Opening In or Out ?

Certain doors, usually in public buildings, are hung to open both ways, and the entrance outer doors in this class of work should always open outwards, a point insisted upon by local by-laws. The reason is very obvious, as otherwise, in case of fire or panic, the pressure of a crowd would render it impossible to open them. In ordinary cases, the general rule for hanging doors is, when open, to shade the room as much as possible (see Fig. 14), but of course there are exceptions, as occasionally in a very small room, if hung in this manner, the door would take up too much space. In some cases it is advisable for the door to open outwards, as in cupboards, etc.

Hanging

Another small matter might be mentioned regarding the hanging of a door. A floor " clearance " is always necessary, but if the modern fashion of a fitted carpet is carried out this clearance must naturally be greater. In some cases a special or rising hinge is employed, which lifts the door clear of the carpet.

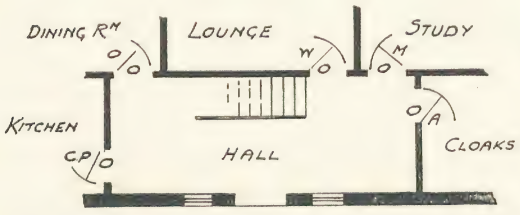


Fig. 14.—PLAN SHOWING REQUIRED FINISHES FOR FLUSH DOORS

Reference : A, Alder. CP, Columbian Pine. M, Mahogany. O, Oak. W, Walnut.

Sliding Doors

Some examples of sliding doors for domestic work are given in Data Sheets Nos. 23 and 24. The sliding door in a number of leaves, which slides round a corner, is a common type for garages. The leaves should never be more than 3 ft. in width. The radius at the corner should be not less than 2 ft.

THE "MOPIN" SYSTEM OF BUILDING CONSTRUCTION

Fig. 1.—Large blocks of flats in course of erection on the "Mopin" system of construction

THE "Mopin" system of construction, which comes to this country from France, employs steel and concrete, the quantity of structural steel required, considering the size of the building, being comparatively small. In some large five-storey blocks of flats, for example, the largest size of steel joist required is 10 in. by 5 in., weighing 30 lb. per foot. As far as possible all the concrete is precast, and is vibrated for a period of about three minutes whilst in the moulds.

Steel Structure

Fig. 2 shows an example of the steel skeleton of a large five-storey block of flats, and Fig. 3 shows a diagram of the general steel construction. It should be noted that besides the main stanchions forming the framework of the external walls, there is a series of stanchions in the interior of the building. These are concealed by the partitions, and are "staggered," not necessarily in the centre of the building, but alternately nearer the front or rear wall.

Each transverse section, with its wind bracing, etc., is bolted together

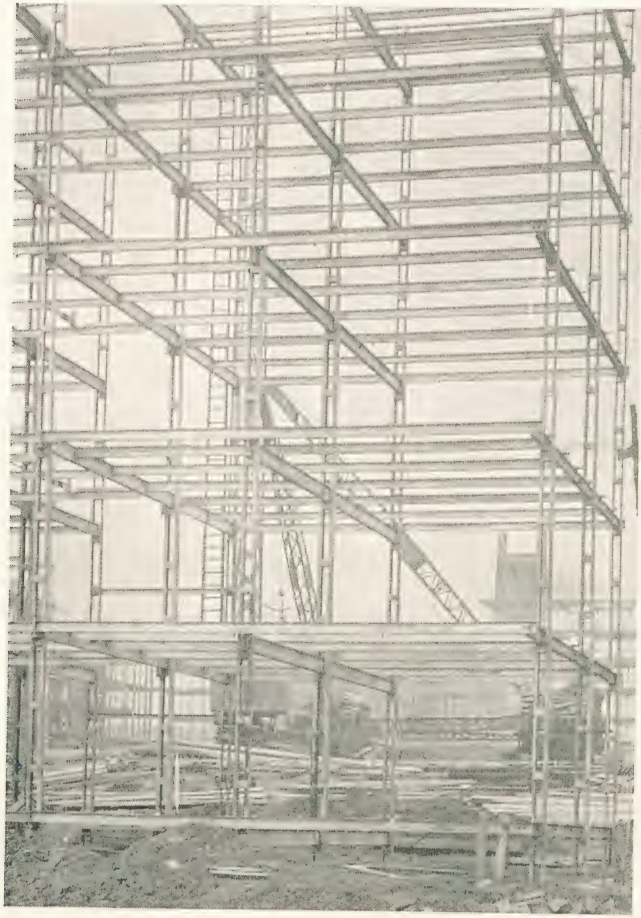


Fig. 2.—STEEL STRUCTURE FOR LARGE BLOCKS OF FLATS TO BE CONSTRUCTED ON THE "MOPIN" SYSTEM

on the ground and set up separately, the longitudinal joists being secured immediately after each section is erected.

The transverse joists are 10 in. by 5 in., and the longitudinal joists at floor level are 8 in. by 4 in. The wind bracing is formed by diagonal ties of $2\frac{1}{2}$-in. by $2\frac{1}{2}$-in. L-irons, bracing and tying the external stanchions with the internal ones. These wind bracings occur only where the "party walls," or divisions between one set of flats and another, coincide.

Steel-and-Concrete Stanchions

Fig. 4 shows in detail one of the main stanchions, consisting of two 4-in. by 3-in. steel channels, secured to each other by cross-pieces welded on at about 3-ft. centres. These stanchions are filled in with vibrated concrete, the process being carried out *in situ*. The size given applies to the lower storey, as smaller stanchions are employed in the upper storey.

Walls

Fig. 4 shows a section of the wall; the reinforced-concrete posts to which the outer wall is attached will be seen. These posts are secured to the steel joists by the usual L-iron lugs.

These panels are not necessarily all the same width, as the distance from centre to centre varies according to the rooms.

The walls consist of 2-in. precast slabs of vibrated concrete as the outer skin. The slabs vary in size, but 4 ft. 6 in. by 1 ft. 6 in. may be taken as a fair average. They are strengthened with ribs cast on, which are reinforced. The slabs are rebated to fit to each other.

The inner skin consists of "Pioneer" slabs $2\frac{1}{2}$ in. thick. The cavity between the inner and outer skins is about 5 in. wide. The two skins are bonded or tied to each other by galvanised-iron ties.

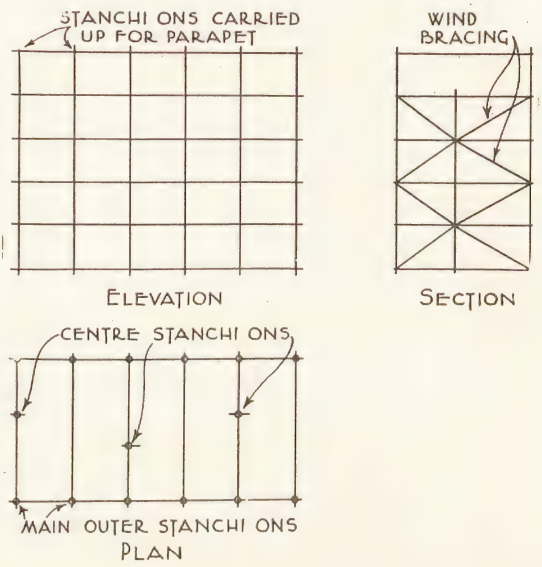


Fig. 3.—Steel structure of building constructed on "Mopin" system

External Wall Finish

Fig. 5 gives a general idea of the appearance of these large slabs, and it will be observed that they do not break joint in the orthodox manner. The slabs are finished externally with either a gravel finish or a spar finish, the aggregate being gauged at about $\frac{3}{8}$ in. Though there is absolutely no attempt to imitate stonework, yet, at a little distance, the general effect is that of large blocks of an extremely coarse granite.

How the Outer Face Is Secured

Fig. 6 gives a drawing of one of the intermediate reinforced-concrete posts, with a series of lugs cast on it (these lugs also are reinforced), and the outer ribs of the slabs are cut away or notched so that they will fit upon the lugs. They are, of course, run in cement.

The piers between the windows are recessed 2 in. from the main face of the

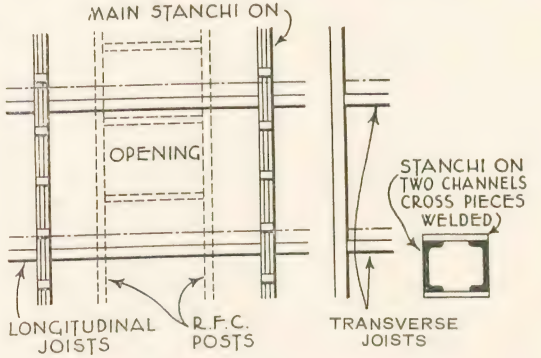


Fig. 4.—Section of wall, showing construction

Note reinforced-concrete posts, to which outer wall is attached. Notice sketch (on right) of stanchion, which is filled in with concrete.

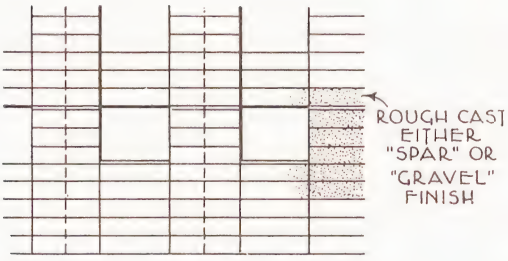


Fig. 5.—GENERAL APPEARANCE OF WALL OF BUILDING

wall. Instead of having lugs cast on, the post is notched in a similar manner to take these recessed slabs. This recessing is not necessitated by the construction, but is only a matter of design.

Windows

Sections of the cill and head are given in Fig. 7. It might here be stated that the cill and head go completely through the wall, and are about $\frac{1}{4}$ in. proud inside. All the window frames are steel. The head, cill, and side posts, being faced concrete and about $\frac{1}{4}$ in. proud of the plaster inside, form a cement architrave.

Partition Walls

The internal partition walls are entirely of " Pioneer " slabs, but in the case of party or division walls between different sets of flats, the partitions are of double thickness, with a 4-in. cavity between, thus forming a 9-in. wall.

Internal Door Frames

The internal door frames are grooved for the slabs, as in Fig. 8, and the frame in this way forms its own architrave.

One advantage of using the slabs is their lightness, as compared with brickwork. They are roughly about half the weight of brickwork per cubic foot, and being thinner than the usual brick

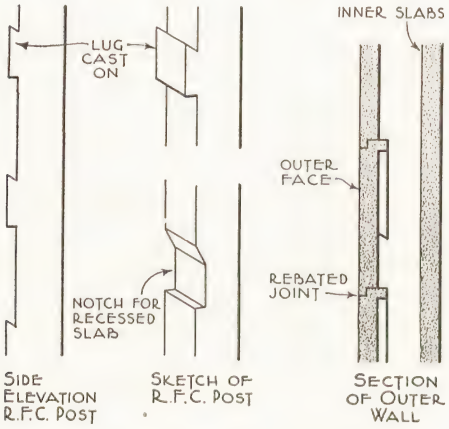


Fig. 6.—CONSTRUCTION OF CONCRETE POSTS AND SECTION OF OUTER WALL

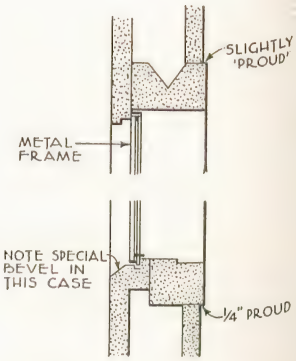


Fig. 7.—HEAD AND CILL

Note that the head, cill, and side posts form a concrete architrave inside.

partition wall, the weight is still further reduced.

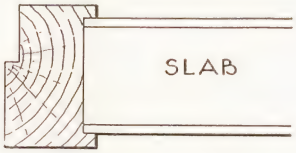


Fig. 8.—INTERNAL DOOR FRAME GROOVED TO TAKE SLAB

Chimneys and Fireplaces

The chimneys and fireplaces are entirely of brickwork, in the ordinary manner, though in some cases a reinforced-concrete beam is required to carry the greater widths of the breasts on the upper floors.

Floors

The floors are constructed of 6-in. by 3-in. rolled-steel joists, resting on the main 10-in. by 5-in. girders. Fig. 9 shows the specially cast "haunches" which rest upon the lower flanges of the six by three's, and in their turn carry the floor slabs. These latter are 4 ft. by 1 ft. 6 in., and from the under side appear to be in six panels (Fig. 9), the ribs, of course, being reinforced. These ribs have a groove on their under side so as to enable them to bed easily upon the haunches before mentioned. The floor is finished with $1\frac{1}{4}$-in. concrete screeding, and after that any floor covering, such as tiles, boards, or whatever other materials may be required, can be employed. This construction is quite strong enough to carry all the normal weight or traffic which any building of the domestic class is likely to be called upon to take.

Ceilings

The ceiling is constructed of 3-in. by $1\frac{1}{2}$-in. wood joists, notched on to the girders, to take the plaster ceiling. The space between the bottom edge of the ceiling joists and the lower flange of the steel joists is utilised to carry the electric tubing.

Roof

The construction of the roof is similar to that of the floors, the finish being in asphalte. The external walls are carried up to form a parapet, and finished with a reinforced-cast-concrete coping.

Staircases

Staircases are constructed of 6-in. by 4-in. reinforced-concrete strings, with lugs cast on to carry the steps. With reference to the steps themselves, the tread and riser are cast as one step, with a triangular rib at each end, and a third one in the centre. A small rib at the back of the tread gives a grip

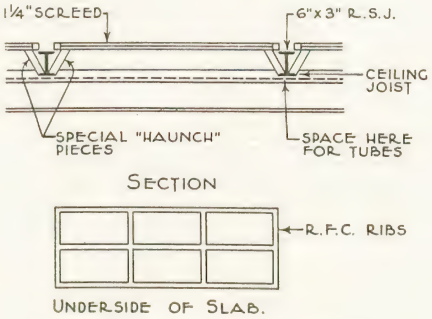


Fig. 9.—FLOOR CONSTRUCTION

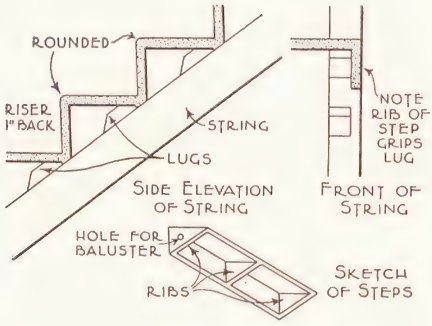


Fig. 10.—STAIRCASE CONSTRUCTION

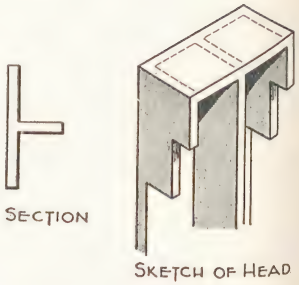


Fig. 11.—STAIRCASE WALL SECTION, AND SKETCH OF HEAD

upon the lugs, as shown in Fig. 10, and at the same time the outer ribs of the steps rest directly upon the sloping strings. The lugs prevent the steps moving sideways. The riser slopes backward about 1 in., which gives a little more toe room. The arris at the edge of the step is slightly rounded, and a hole is left in the outer rib to take the iron baluster.

It is scarcely necessary to state that the wood model of the string, and after that the mould from the same model, must be very carefully and accurately made, both to place the lugs in their correct position and to obtain the slope with perfect accuracy.

The staircase walls differ somewhat from both the external and the internal walls, as they have more weight to carry, such as the landing beams, which in their turn carry the strings. These walls are formed with large slabs about 9 ft. by 12 in. wide. They are made in a T-section, the centre rib stiffening the slab. Fig. 11 illustrates this, and also shows the small brackets at the top which are required to form a base to continue through the upper storeys. These slabs are secured to the transverse beams by iron rods. The finish of these walls on the staircase side is similar to the external walling, whilst the inside is lined with the "Pioneer" slabs as usual.

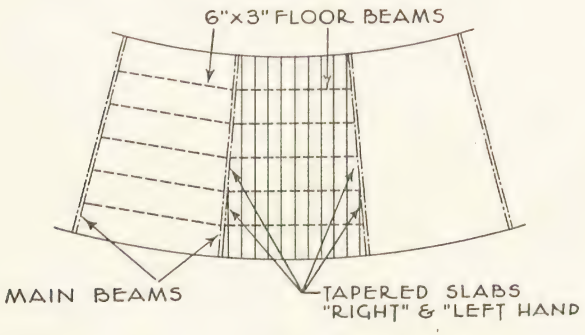


Fig. 12.—CIRCULAR FLOOR

Circular Work

When the main transverse beams are radiating, as in circular work, it is necessary that some of the floor slabs be tapered (see Fig. 12), and also tapered in pairs both right and left hand.

ENTRANCE GATES

THE choice of materials for entrance gates is more limited than in most building operations, the principal being wood or iron, though in cases where expense is no object, a more costly material, such as bronze, is occasionally used.

Barred Gates

The simplest form of a gate is the ordinary field gate. It is usually constructed of five horizontal bars (five-bar gate), housed and pinned into two uprights. The uprights and top rail are fairly substantial, about $3\frac{1}{2}$ in. by $2\frac{1}{2}$ in., the four other rails being about 3 in. by $1\frac{1}{4}$ in.

The gate being 8 or 9 ft. wide, there is a heavy leverage on the hinges, particularly the upper one. Extra support is therefore given to the outer stile by a raking strut from the point of support of the bottom hinge, or, alternatively, a raking tie from the top hinge. Fig. 1 shows both methods.

If the gate be wide, sometimes a vertical bar is nailed in the centre. Excellent examples of this method of strengthening very large and heavy gates may be seen at railway level-crossings. In these cases, the gate is constructed of very substantial timbers, with two or three intermediate uprights with struts from one to the other, and over all a pair of strong iron bars as ties from the top hinge (see Fig. 2).

Fastenings for Field Gates

The usual type of hinge for the ordinary field gate is a crook driven into the post, and a wrought-iron strap, with a loop, bolted through the top rail. It is better if a " clasp " hinge is used (Fig. 5A), with a strap on each side of the top rail. As there is less strain on the lower hinge, it is usual to employ a smaller one. The spring fastener is the most common type (Fig. 4).

An improved type of field gate is occasionally used when only a single gate is required, as the entrance for vehicles, but in this case it is of a better construction, the three intermediate horizontal bars being made of iron tubing ; the clapping stile is secured to the top and bottom rails with iron straps, and the whole construction is after the pattern of the railway-crossing gate.

Paling Gates

The paling gate makes a serviceable gate if oak is used. The palings should be fixed with copper nails placed, or driven home, checkwise.

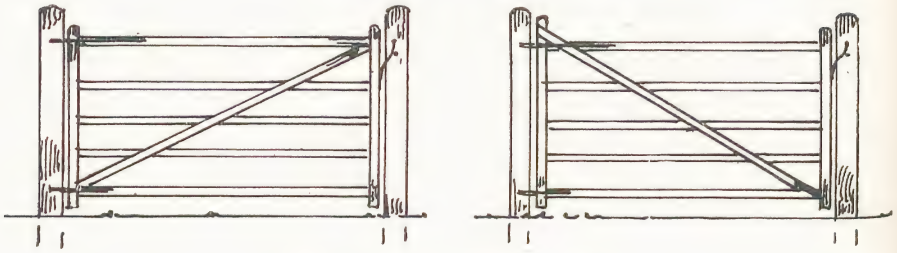


Fig. 1.—FIVE-BAR FIELD GATES
Example with diagonal bar used as strut on left, and as tie on right.

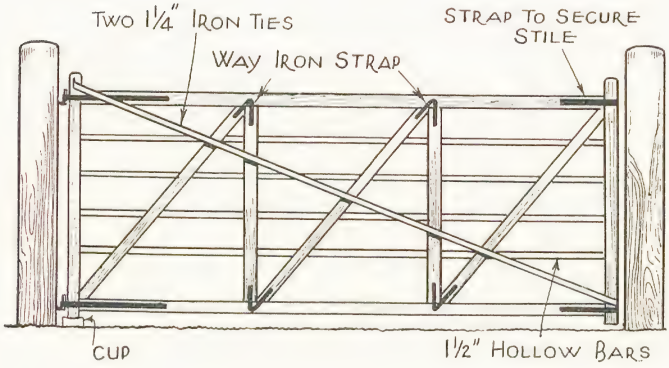
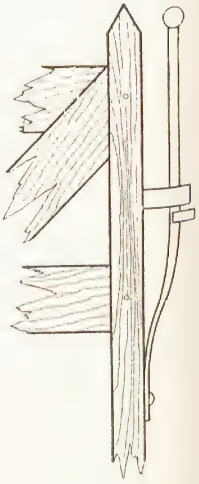


Fig. 2 (*left*).—LEVEL-CROSSING GATE



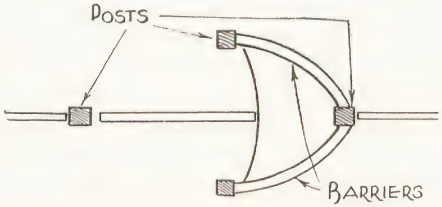


FIG. 5.—KISSING-GATE

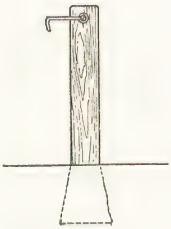
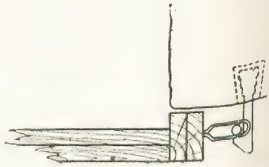


FIG. 3 (*left*).—IRON CATCH FOR FASTENING FIELD GATE WHEN IT IS OPEN

Fig. 4 (*right*). — SPRING CATCH ARRANGEMENT FOR FIELD GATE
Note catch secured in stone post.



Horizontal bars are used, housed into upright posts or stiles. Brace-pieces are used to strengthen the gate. As a general rule, the hanging stile is wider than the closing stile of the gates. Palings should be spaced out suitably to receive the bolts for the bands, in order to avoid packing-pieces between the palings.

Kissing-gate

Another type of gate, though it can be used only for a footpath, is one which in some parts of the country is called a " kissing-gate " (Fig. 5). This consists of a small gate hung to swing either way, and without a fastener. There is a barrier each side, and the width being narrow, it is obvious that only one person can pass through at a time. With a gate of this kind it is impossible for cattle to stray from their pastures.

Small-house Wooden Gates

The entrance to the small house or semi-detached villa usually consists of a pair of gates about 8 ft. wide, or a wicket-gate about 3 ft. wide, or both, though in many cases the latter is redundant. It is a very common practice, in the case of a pair, to make them of unequal widths, say 3 ft. and 5 ft. respectively, the smaller one to act as the wicket, a 3-ft. gate being less cumbersome to open than one 4 ft. wide. The ordinary visitor will use the wicket, both gates being opened only when required to admit a vehicle.

With reference to the design of the gates, it should be in accordance with the general design of the railings or fence, though in some cases they are a little more pretentious. An example is shown in Fig. 6. These gates are framed in the ordinary manner, the lower part being filled in with boards and the upper portion being open, with simple square balusters. It is utterly useless to discuss the question of design in general, as there is an absolutely endless variety of choice in the matter.

Needless to say, a wooden gate is usually hung to a wooden post by the simple hinges already described. If the gate be large, and liable to cause a heavy strain on the hinge, the crook should be bolted right through the post, and secured with a nut and large washer.

In some cases concrete posts are employed. If so, the crook should always penetrate through the post.

Fastenings for Small Entrance Gates

The general method of securing these gates is simple in the extreme. A strong wood block is let into the ground to act as a stop, to which the large gate is bolted, and the smaller one fastened with the usual sneck. In many cases the small gate has a spring attached, to prevent its being left open by careless callers. It is a common practice for the average entrance gate to be hung 3 or 4 in. clear of the ground, and this is absolutely necessary if the path inside inclines upwards at all ; or, on the

other hand, special hinges can be obtained which lift the gate slightly as it is opened.

One can see to-day many examples of the cast-iron gate so popular in the last century, but this has generally given way to wrought iron for the same purpose, and as an example of what was done fifty years or so ago one has only to turn to the old catalogues of some of the well-known foundries to see the most elaborate patterns. In these cases the gates are invariably hung to cast-iron posts.

Wrought-iron Gates

In this age, the gates, if not of wood, may be taken as wrought iron, whether it be the single wicket-gate or the more imposing pair. They should naturally be in accordance with the adjoining railings.

Fig. 7 shows a light iron gate hung to an iron standard. The standard carries a pair of crooks similar to those described for the wooden field gate, and these are either welded on or riveted through the standard. In the same way, the gate has a pair of loops, and can be simply dropped on to the crooks. To stop a gate being lifted off, a nut can be screwed on to one of the crooks. In a case like this, the standards should be fairly substantial, and stayed either to the railings or with an oblique stay, or both.

Hinges and Fastenings for Iron Gates

Gates, however, of both iron and wood, are occasionally hung direct to a pier of masonry or brickwork, posts or standards being dispensed with. In this case the crooks are built into the pier, or a mortice is cut in the hanging-stone, and the crook run with lead. This does not always prove satisfactory. In the first place, the crook may work loose with the constant shutting. Secondly, the strain on the upper hinge may pull the hanging-stone out of place (see Fig. 8). This strain, however, can be considerably reduced by the hanging stile of the gate being let in about 1 in. into an iron cup, which in turn is sunk into a large stone or threshold.

Fig. 9 shows how a gate may be hung without hinges at all, in the ordinary sense. The lower end of the hanging stile is let into the cup. Instead of the upper hinge, a large plate is bolted through the pier. This plate carries a bracket with a hole pierced through it. A loop encircles the stile of the gate and is bolted through the bracket. A packing-piece is inserted in the loop, so as to give sufficient "play" for the stile to work, and the stile itself, about $1\frac{1}{4}$ in. square, is hammered circular for the small portion which passes through the loop. For a heavy gate like this, the pier must be exceptionally strong, but the same system is sometimes employed for lighter gates.

In the case of heavy gates further help can be given to the hinges by a metal "race." This consists of a bar of wrought iron about 2 in. wide, made in a quadrant curve, exactly the radius required by the swing of the gate. On the outer stile of the gate a small wheel is fixed, which runs

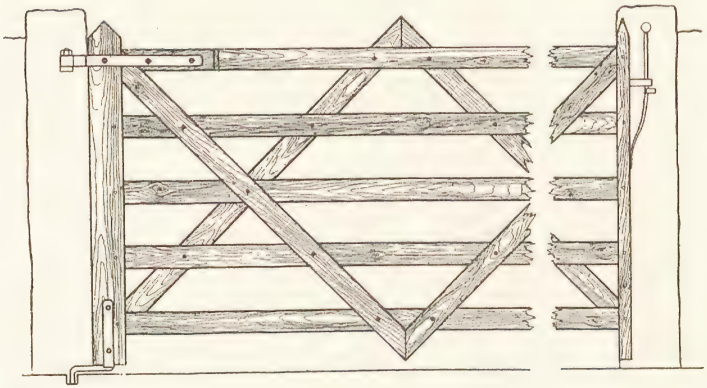


Fig. 5A (*right*).—FIVE-BAR GATE WITH ATTACHMENTS

Thickness of upright pieces, 3 in. Bars, 1 in. thick, housed into uprights and pinned. Cross-braces also 1 in. thick.

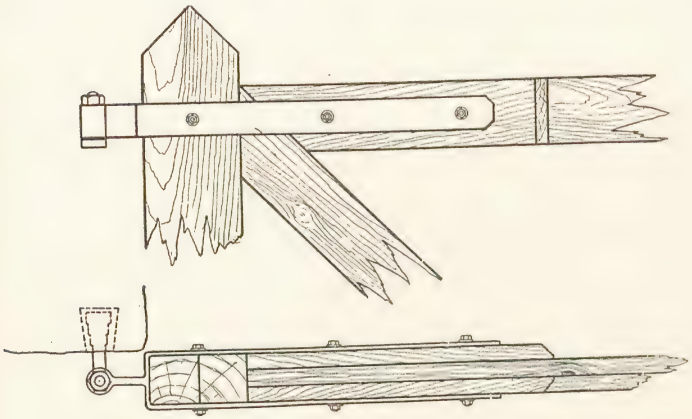


Fig. 5B (*left*).—BAND AND CROOK HINGE

Crook is secured to stone pillar with lead. Band comes well on to gate, and is secured to crook with locking nut.

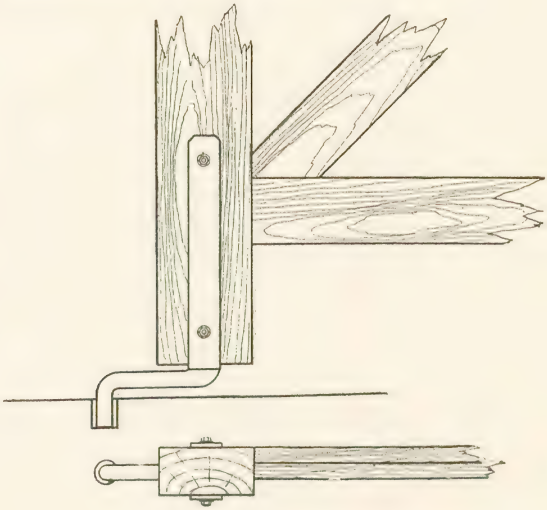


Fig. 5C (*right*).—BAND HINGE AT BOTTOM OF FIVE-BAR GATE

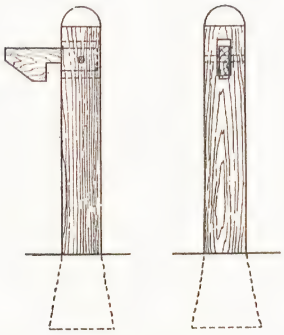


Fig. 5D.—ALL-WOOD GATE CATCH FOR FASTENING FIELD GATE WHEN OPEN

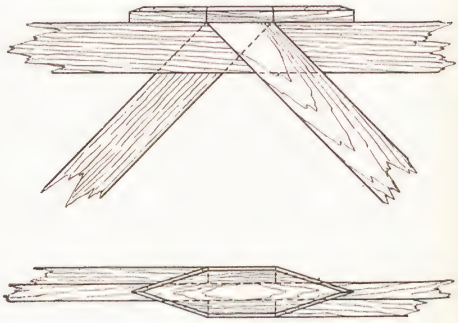


Fig. 5E.—CAP FOR CROSS-BRACES AT TOP OF FIELD GATE

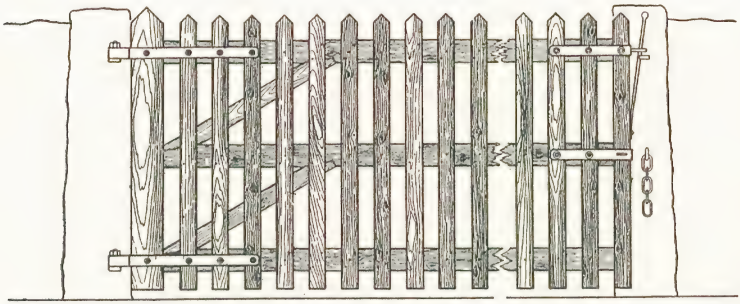


Fig. 5F.—PALING GATE WITH STONE POSTS

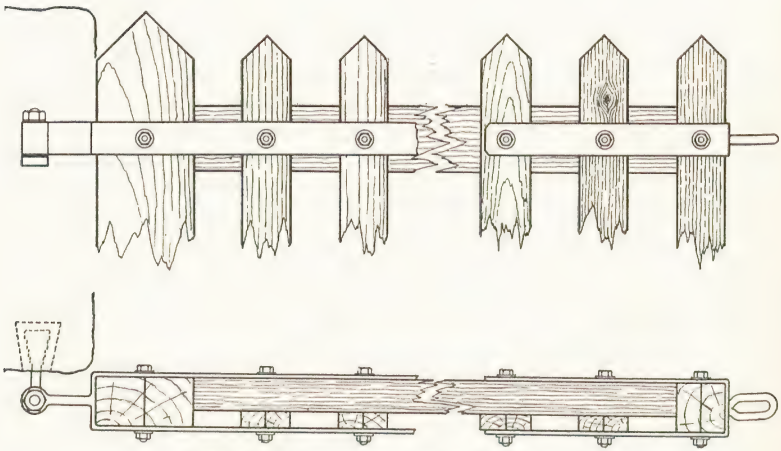


Fig. 5G.—CONSTRUCTION OF PALING GATE

easily upon the quadrant and must naturally take a great share of the weight and ease the strain on the hinges to a very large extent.

Quadrant Entrance

Fig. 13 shows a plan of the imposing quadrant entrance, reminiscent of the spacious Georgian days. The gates are set well back from the high road, with stalwart piers and a wicket-gate on either side. In modern practice, where it is necessary to give sufficient room for cars to enter, a simple form of the quadrant entrance is employed.

Iron Standards

It is not uncommon to use an iron standard either in place of, or in addition to, the stone pier. This may consist of a 12-in.-square standard formed of four stout uprights, braced together either by diagonal bars or by scrolls. Fig. 11 gives an example of one of these. Occasionally they perform an additional duty by carrying a lamp, and particularly in the case of entrances to public parks, they often carry an iron arch from one to the other, a lamp being suspended from the centre.

Usually, these more important gates are supplied with locks, a spring catch to hold the gates open when necessary, and a lift-up stop to hold one gate, which is then bolted, and the other secured to it.

In the hanging and arrangement of the types of gates we have mentioned, certain points must be stressed, such as the liability of the large gate to sag, the necessity for building or bolting all crooks (or whatever may be used) well into the masonry piers, properly staying or strutting all iron standards, and keeping all frictional parts well oiled.

Collapsible Gates

The collapsible gate is useful in the outer entrances of some buildings where space will not allow the gate to swing inwards. This class of gate can either run on the lower bar or be hung from the upper one, and in these cases the bars may be permanently fixed. In the case illustrated (Fig. 14), after the gate is collapsed the top bar is let down and the lower one lifted, and the gate is so hinged as to swing entirely to one side and allow the maximum of space in a confined entrance.

There is also a type of gate which reminds one of the old portcullis. Whereas the latter was let down, obviously, by a series of counterbalancing weights, there can now be obtained gates which, in order to open, are let down into a cavity formed in the foundations. These are useful in closing the entrance to a shopping arcade at night time. When let down, the cavity is closed by small metal lids.

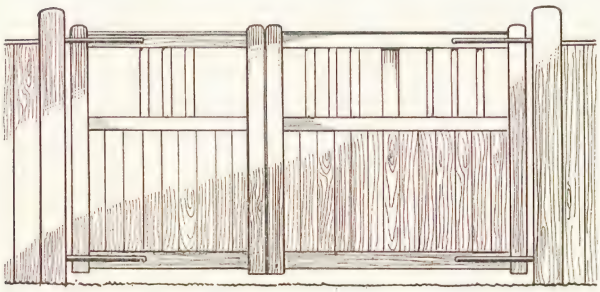


Fig. 6.—WOODEN ENTRANCE GATES

Fig. 11.—IRON STANDARD

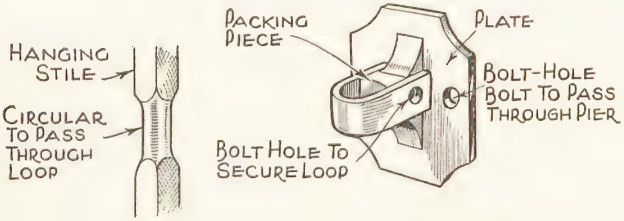


Fig. 9.—PLATE AND LOOP HINGE FOR IRON GATE

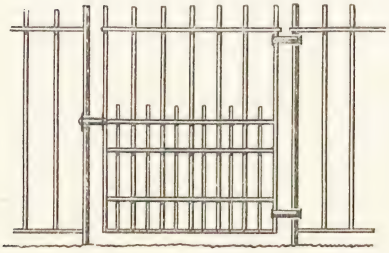


Fig. 7.—IRON WICKET-GATE

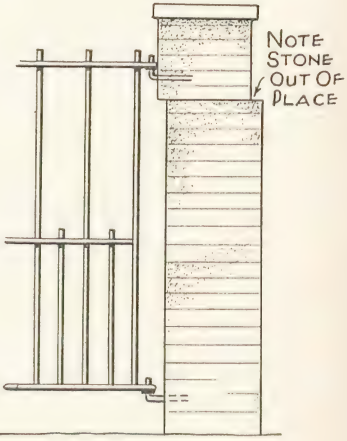


Fig. 8.—PULL OF GATE ON PIER

The strain on upper hinge may pull pier out of place.

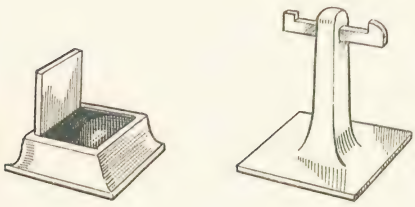


Fig. 10.—STOP AND CATCH FOR IRON GATE

Fig. 12.—ENTRANCE GATES AND FENCE, "BOURNE GAP," WINDSOR
(*Architect: Alexander E. Matthew, L.R.I.B.A.*)

Materials

Oak, without a doubt, is the ideal for any purpose. Pitch-pine does not lend itself, as it does not take paint well. Red deal, free from large knots, takes paint well and is lasting. For gates connected with agriculture, larch is very adaptable and is used considerably, though the tendency of the material is to twist and twine.

Details of Construction for Framed Gates

Strength of morticed and tenoned framed work depends largely on the thickness of the tenon. It is safe to work on one-third the thickness

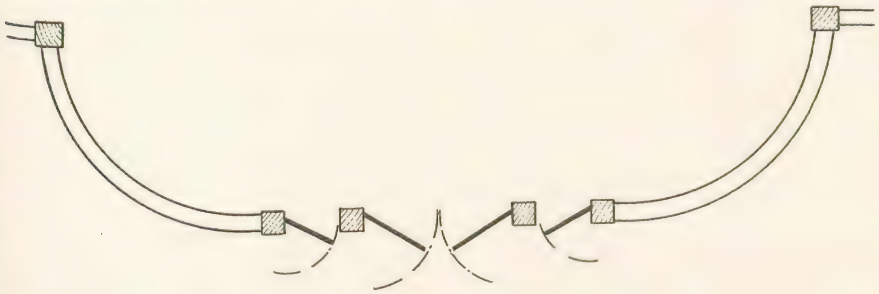


Fig. 13.—THE QUADRANT ENTRANCE

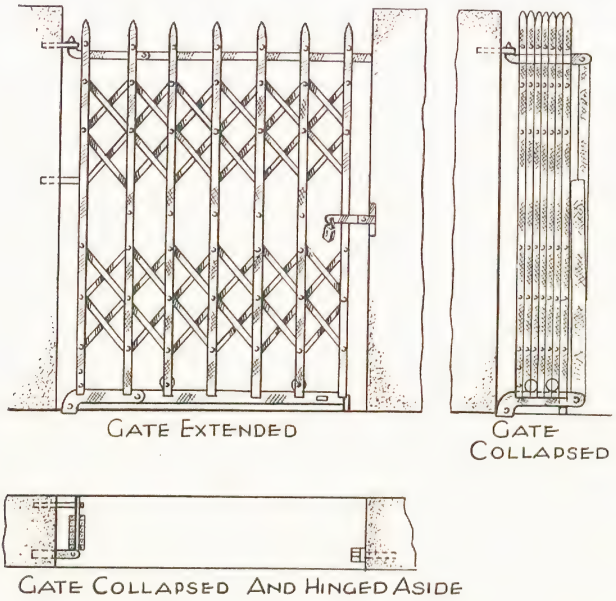


Fig. 14.—COLLAPSIBLE GATE

After the gate is collapsed, the top bar is let down and the lower one lifted, and the gate is so hinged as to swing entirely to one side.

of the material, or slightly under one-third the thickness of the material.

Pins should be used in the connection of rails and stiles. Draw-pinning should be done, but only slightly: it helps to pull the joints together.

It is a very common practice to allow the stiles to be longer than the top of the top rail. These are often called, in the North of England, "lugs." The rail should not be tenoned the full width, but where the lug is, a little haunch should be used.

The middle rail should be morticed and tenoned like the middle or cock rail of a door, and in spacing out the tenons make the haunch portion slightly over one-third the width of the rail. In most cases the handles for the gates are fixed right in the centre of the connection between these centre rails and stiles, with the result that the portion here is very much weakened just at a point where the maximum strength is required. The haunch portion is quite deep enough if it is, say, ½ in. long.

The bottom rail connection should be divided into two portions, that forming the tenon portion rather wider than the haunch. All the three rails should be pinned.

In gates framed and morticed together, cross-brace where possible.

FOUNDATIONS FOR PIERS, COLUMNS, AND WALLS

PLAIN-CONCRETE FOUNDATIONS

WHERE the loads are comparatively light, or where they do not need to be spread over a large area, plain-concrete footings may be used. In two-storey, semi-detached houses, the load at the base of the external walls is about 1 ton per foot run, and at the base of the party wall about 2 tons per foot run. Assuming that the ground will carry 1 ton per square foot, a mass-concrete footing 2 ft. wide will carry both external and party walls.

It is usually laid down in the design of mass-concrete footings that the thickness of the concrete shall be such that the load can " spread " to the outside edges of the footings at an angle not flatter than 60°. In large footings, layers of old rails are generally added. These are put in by eye and without any attempt at calculation.

Fig. 1 shows a plain-concrete wall footing, and Fig. 2 shows a plain-concrete cap on a group of sixteen timber piles. The construction in Fig. 2 is unusual nowadays, as reinforced-concrete piles with a reinforced-concrete cap would generally be employed.

REINFORCED-CONCRETE COLUMN FOOTINGS

A spread footing for a cast-iron or steel column or for a heavily loaded isolated pier is often built of reinforced concrete. Figs. 3 to 11 show a series of spread footings designed to carry loads of 25, 50, and 100 tons, spread at $\frac{1}{2}$, 1, and 2 tons per square foot.

Checking Shear and Bending Strengths

In calculating these footings, the shear strength and the bending strength must be checked. The footings in Figs. 3 to 13 have been designed for a safe punching shear stress of 150 lb. per square inch, a safe beam shear stress of 75 lb. per square inch, a safe compressive stress of 750 lb. per square inch on the concrete, and a safe tensile stress of 18,000 lb. per square inch on the steel. To check the punching shear, we assume that the column may punch a clean hole right through the footing slab. Thus, in Fig. 11, if the column base is 19 in. by 19 in., and the footing is 21 in. thick, the column might punch a hole 19 in. square right through the footing. This hole would have four sides each 19 in. by 21 in., and the total area in punching shear would be—

$$4 \times 19 \times 21, \text{ or } 1{,}600 \text{ sq. in.}$$

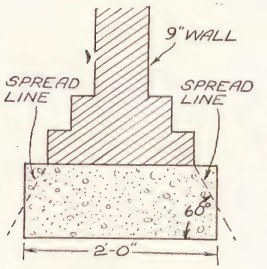


Fig. 1.—A PLAIN-CONCRETE WALL FOOTING FOR TWO-STOREY, SEMI-DETACHED HOUSE

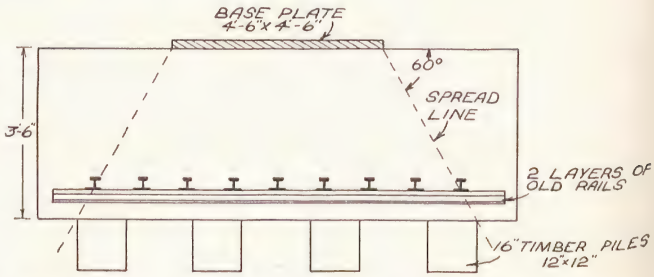


Fig. 2.—A PLAIN-CONCRETE CAP ON A GROUP OF SIXTEEN TIMBER PILES—UNUSUAL CONSTRUCTION IN PRESENT-DAY PRACTICE

With a safe punching shear stress of 150 lb. per square inch, the resistance to punching shear is—

$$1{,}600 \times 150 \text{ lb., or } 108 \text{ tons.}$$

The *punching* shear can be calculated only on a clean vertical hole, and outside "spread" lines at 45°, the footing must be checked for *beam*-shear strength. If, in Fig. 11, we assume that the column may break through the footing slab on the lines *a-a*, *b-b*, there will be four areas in shear, each 5 ft. 1 in. by 1 ft. 9 in. deep. The effective depth of the footing is about 19 in., and the lever arm about 0·857 by 19, or 16·3 in. The total safe beam shear on these four areas, at 75 lb. per square inch, is—

$$4 \times 61 \text{ in.} \times 16{\cdot}3 \text{ in.} \times 75 = 298{,}000 \text{ lb.} = 134 \text{ tons.}$$

The actual shearing force is something under 75 tons.

Coming next to the bending strength, it is clear that the *total* bending moment on a vertical section through the centre line is very nearly equal to half the load on the footing multiplied by one-quarter of the width of the footing. In Fig. 11, if we cut the footing in two we have a section of concrete 8 ft. wide at the top (or compression) side, reinforced with thirty-seven bars of $\frac{3}{4}$-in. diameter. The total bending moment is very nearly 50 tons at a distance of 3 ft. 6½ in., or—

$$50 \times 2{,}240 \times 42{\cdot}5 \text{ in.} = 4{,}760{,}000 \text{ lb. in.}$$

The safe bending strength of the section, as far as the compression on the concrete is concerned, is—

$$138 \times 96 \text{ in.} \times 19^2 = 4{,}800{,}000 \text{ lb. in.}$$

The minimum area of steel required is—

$$\frac{4{,}760{,}000}{18{,}000 \times 16{\cdot}3 \text{ in.}} = 16{\cdot}3 \text{ sq. in.}$$

Each $\frac{3}{4}$-in. bar has a section of 0·4418 sq. in., so that thirty-seven bars will be required, as shown.

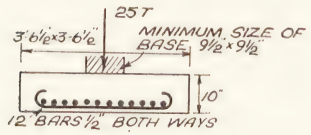


Fig. 3.—25 TONS SPREAD AT 2 TONS PER SQUARE FOOT

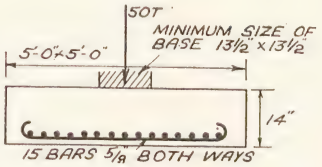


Fig. 6.—50 TONS SPREAD AT 2 TONS PER SQUARE FOOT

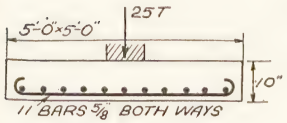


Fig. 4.—25 TONS SPREAD AT 1 TON PER SQUARE FOOT

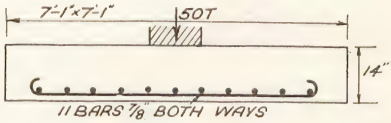


Fig. 7.—50 TONS SPREAD AT 1 TON PER SQUARE FOOT

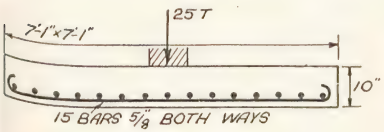


Fig. 5.—25 TONS SPREAD AT ½ TON PER SQUARE FOOT

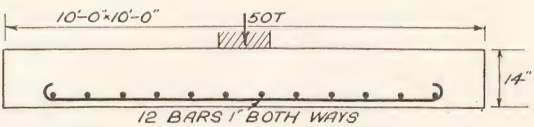


Fig. 8.—50 TONS SPREAD AT ½ TON PER SQUARE FOOT

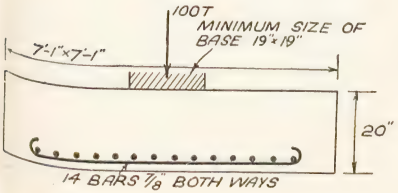


Fig. 9 (*left*).—100 TONS SPREAD AT 2 TONS PER SQUARE FOOT

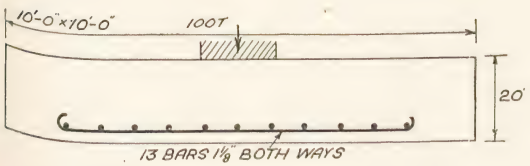


Fig. 10 (*left*).—100 TONS SPREAD AT 1 TON PER SQUARE FOOT

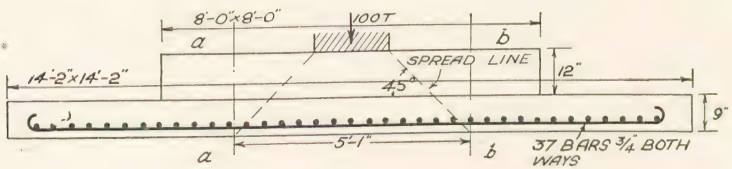


Fig. 11.—100 TONS SPREAD AT ½ TON PER SQUARE FOOT

Figs. 3 TO 11.—REINFORCED-CONCRETE SPREAD FOOTINGS FOR CAST-IRON OR STEEL COLUMNS OR HEAVILY LOADED ISOLATED PIERS

Stepped Footings

Only in the case of a number of large footings is it worth while to make a stepped footing as in Fig. 11. In all other cases, plain rectangular slabs with flat tops, as in Figs. 3 to 10, are best. If stepped footings are used the upper part must be added within a few hours of concreting the lower part, and the joint must be kept scrupulously clean.

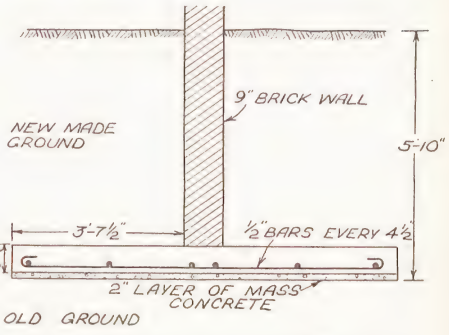


Fig. 12.—REINFORCED-CONCRETE WALL FOOTING SLAB

Showing 9-in. wall with load of 2 tons per foot run at base. Ground at depth of 5 ft. is capable of carrying about 10 cwt. per square foot gross weight.

WALL FOOTINGS

Reinforced-concrete Footing Slab for 9-in. Wall

When it becomes necessary to spread the load from a wall over more than about 5 ft., a reinforced-concrete footing slab may be used. Fig. 12 shows a 9-in. wall with a load of 2 tons per foot run at the base of the wall. The ground, at a depth of 5 ft., is capable of carrying about 10 cwt. per square foot gross weight. The earth above the foundation slab weighs about 5 cwt. per square foot, leaving only 5 cwt. per square foot net available for the load on the wall. The footing slab must therefore be 8 ft. wide. The slab is designed as a cantilever of 3-ft. 7½-in. span carrying an effective upward load of 5 cwt. per square foot. A 6½-in. slab reinforced with ½-in. bars at 4½-in. centres is suitable for these conditions.

Footing for 14-in. Wall

A similar footing, but for a 14-in. wall having a load of 6 tons per foot run at the base, is shown in Fig. 13. In this case the ground at a depth of 4 ft. will carry 1 ton per square foot gross. Deducting 4 cwt. per square foot for the weight of filling over the foundation slab, this leaves a net amount of 0·8 ton per square foot, and the footing slab should be 7 ft. 6 in. wide. If the ground is slightly variable, or if the loading on the wall

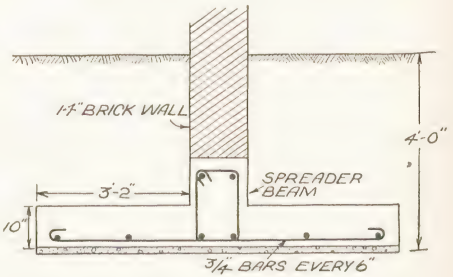


Fig. 13.—FOOTING SLAB FOR 14-IN. WALL

Load, 6 tons per foot run at base of wall. Ground at depth of 4 ft. will carry 1 ton per square foot gross.

is not quite uniform, a spreader beam may be formed, as shown. The size of this beam can generally be calculated to suit the loading on any given site.

Preliminary Concrete

Before constructing any reinforced-concrete foundations or footings, a layer of mass concrete about 2 in. thick should be spread over the site. This has been shown in Figs. 12 and 13, but is not shown in Figs. 3 to 11.

FOUNDATIONS ON BAD GROUND—RAFT FOUNDATIONS

Alternative Sites

It has happened in the past that a prospective building owner has purchased a plot of low-lying ground at what he considered a bargain price, only to find himself involved in heavy expenditure on difficult and expensive foundations. If called in sufficiently early, the engineer or architect should point out that it may be cheaper to purchase a more expensive plot on a drier and firmer site.

When a Raft Foundation is Required

When the ground is so soft that the footings to walls and columns are so large that they touch one another, then the foundations may be all joined together into one raft which will spread the whole weight of the building uniformly (or very nearly so) over the whole site. A very similar state of affairs may occur on a moderately good site with a very heavy building, such as a grain silo weighing 2 to 3 tons per square foot on plan.

The term " raft " is often very loosely used, and is sometimes applied to any reinforced-concrete slab resting on the ground (such as a 6-in. basement floor slab), but the writer intends to discuss only those cases where a large reinforced-concrete foundation is definitely designed and calculated to spread foundation loads over large areas.

Before deciding on a raft, the engineer must ascertain if there is harder ground at a lower level which could be reached by mass-concrete piers or by piles. On the other hand, the excavation and pumping required for pier holes, or the vibration due to piling, may endanger surrounding buildings, and leave the engineer no alternative but to supply a raft foundation put in at the highest possible level.

Examination of Site

The larger the area of the raft the more danger there is of a deep-seated and general movement of the ground, and a far-reaching examination of the site is necessary.

We may commence by examining the surrounding sites. If there are existing structures on adjoining land, we can see if they have settled

appreciably, and can possibly find out what kind of footings they stand on. If there are strong gradients, railway cuttings, canals, rivers, or similar features within 100 ft. of the boundary of the site, their positions and depths should be noted. All parts of the raft must be kept behind and below a line drawn at 20° to the horizontal through the deepest point of any neighbouring depression.

This is necessary to prevent the ground from squeezing out laterally.

Boreholes and Trial Holes

The next step is to have a borehole put down, say, 40 ft. deep. This will cost about £50, and is a very wise form of insurance even on a small site. The borehole will show the general nature of the site, but will not show the compactness and strength of the strata through which it passes. If the bore shows running sand or peat, then danger is at once indicated. If, on the other hand, the bore shows something hard (such as coarse ballast), the possibility of piling down to this level suggests itself.

Three or four trial holes should next be dug down to a level 6 ft. or 8 ft. below the under side of the proposed raft, and rods (say, pieces of 1-in.-diameter bar, or $1\frac{1}{4}$-in. gas-barrel, or pieces of fencing angle or anything that happens to be available), should be driven down vertically with a 14-lb. sledge-hammer through the bottom of each hole. These rods should be 10 ft. or 12 ft. long, so that their points reach 15 ft. to 20 ft. below foundation level.

If the borehole does not indicate any dangerous strata ; if the ground exposed by the trial holes is no worse than the ground at foundation level ; and if the trial rods, while being driven, meet with steady or increasing resistance, then all is well, and a raft foundation may be put in. But if the borehole shows running sand or peat ; if the ground in the trial holes is softer than the ground higher up ; if large quantities of ground water are encountered, or if the trial rods reach soft patches during driving, then an expert must be consulted.

Those of us who may be called on as part of our daily routine to give opinions on the bearing capacity of sites develop in time a sort of thumb-technique of the subject which no one has so far been able to express in exact mathematical terms.

Fixing Safe Load under a Raft

In fixing the safe load under a raft we must remember that the larger the raft the smaller the load per square foot must be. A deep bed of fairly compact yellow or brown clay or loam will safely carry 2 to 3 tons per square foot on small isolated footings, say, less than 10 ft. square. Good blue clay will safely carry 4 tons per square foot on similar small footings. The pressure under a raft about 50 ft. square should not exceed three-quarters of the foregoing figures, while the pressure under a raft 100 ft. square should not exceed about two-thirds of them.

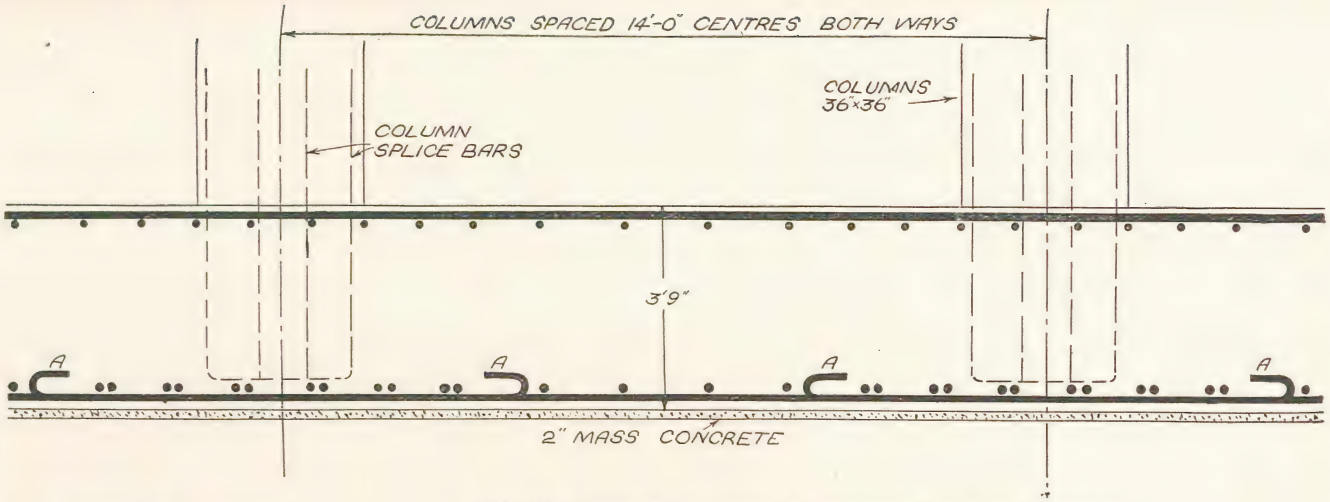


Fig. 16.—Section through foundation raft for grain silo

Bars A are 25 ft. long and overlap to give six pairs in both directions under each column. All other bars laid in long lengths and overlapped 4 ft. 6 in. All bars are $1\frac{1}{8}$ in. diameter and to have round hooks both ends.

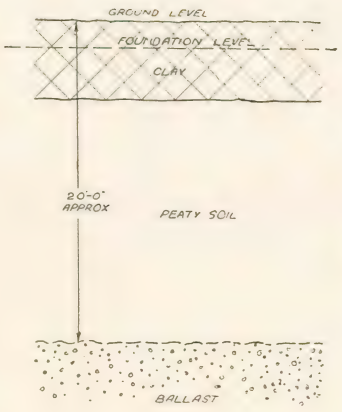


Fig. 14 (*left*). — Example of site unsuitable for raft foundation

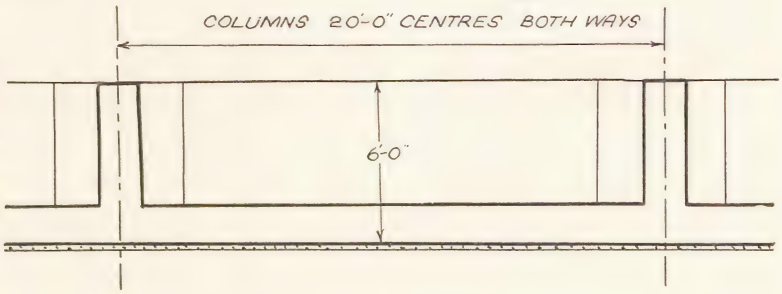


Fig. 15 (*right*).—Section through one bay of raft for large office building, capable of spreading stanchion loads over site at 1 ton per square foot

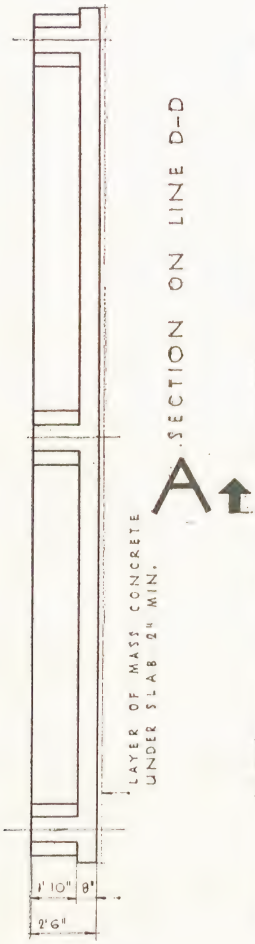


Fig. 19.—SECTION D-D OF FIG. 17

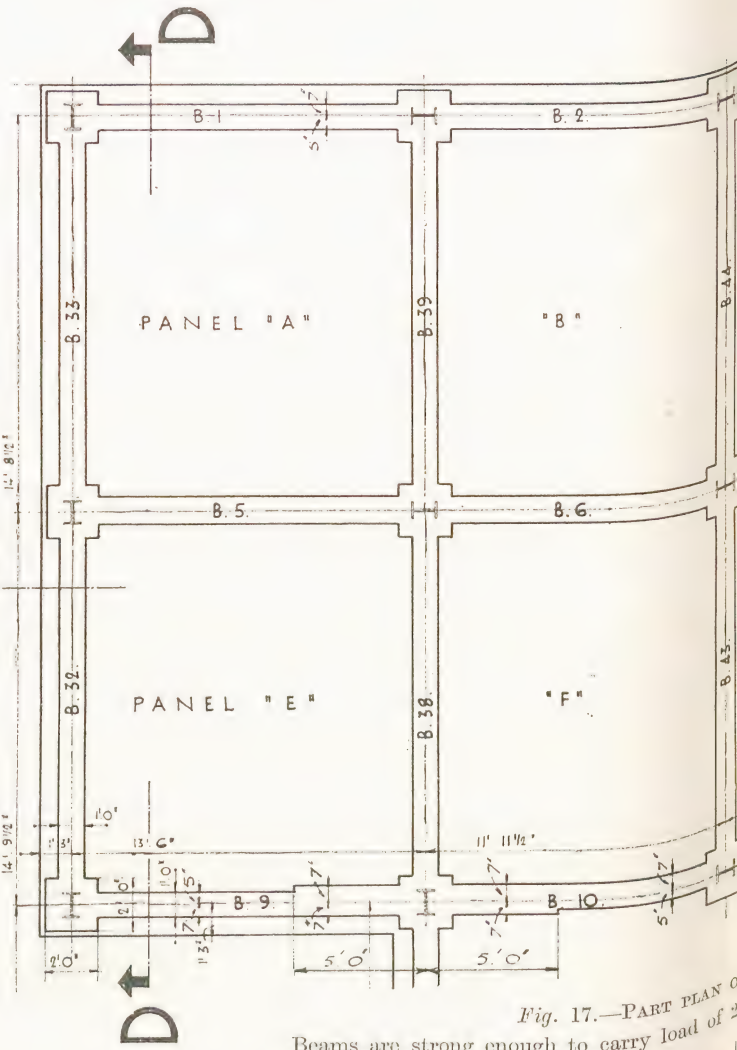
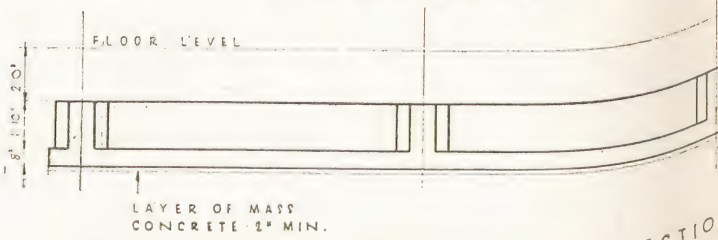


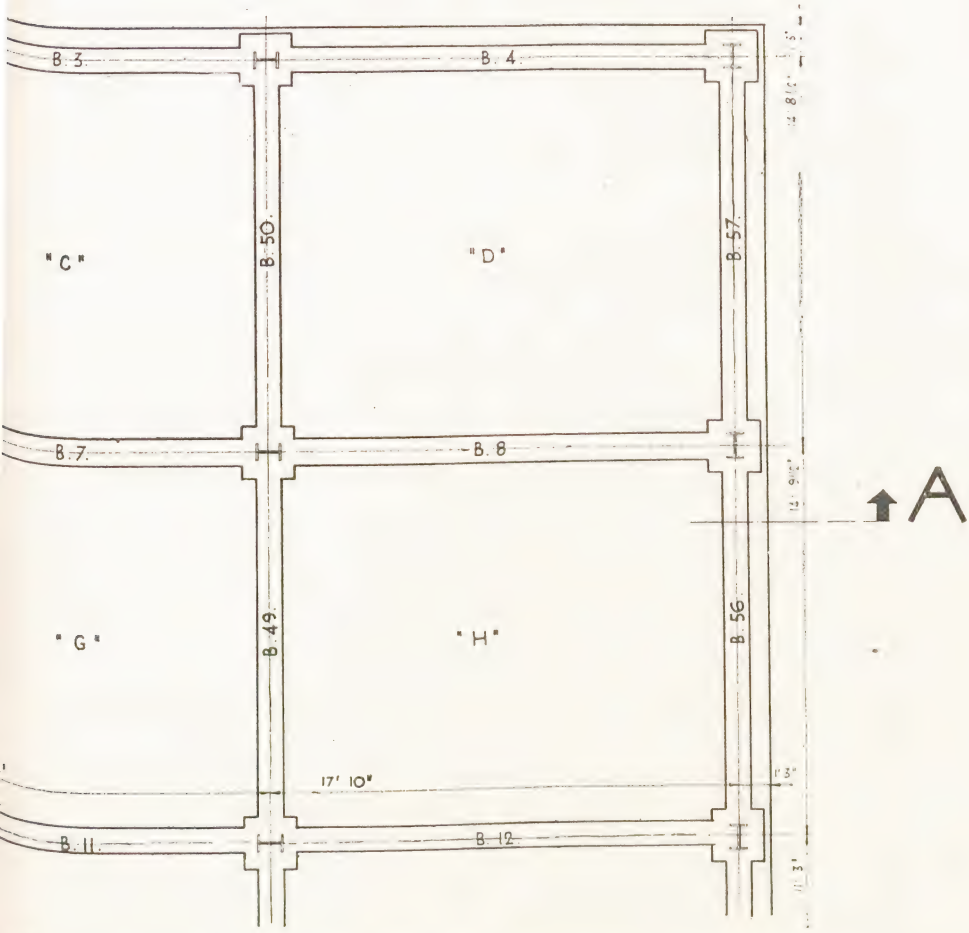
Fig. 17.—PART PLAN O

Beams are strong enough to carry load of 2



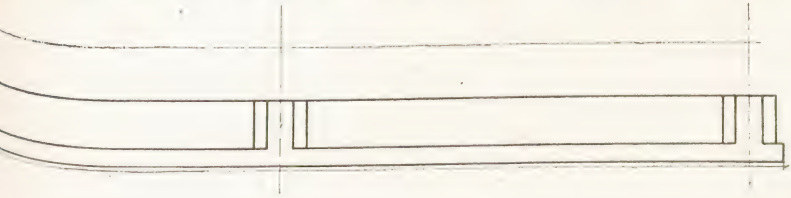
SECTIO

Fig. 18.—



FOR THREE-STOREY SHOP AND OFFICE BUILDING

er ft. run, while slab will spread load uniformly over site at 6 cwt. per square ft.



N LINE A—A

A-A OF FIG. 17

Loading Tests

If there is doubt about the local strength of the ground at foundation level, a block of concrete about 5 ft. square and 2 ft. thick should be put in at this level, and should be loaded with one-quarter of its final load every other day. It should carry its final load for seven days with a settlement of less than ½ in. Suppose that the site is required to carry a large raft loaded to 2 tons per square foot. The ground must be able safely to carry 3 tons per square foot on a small area, and must support a test load of 6 tons per square foot for seven days with a settlement of less than ½ in.

Loading tests are expensive, and carried out only when the owners want to load the ground beyond the limit which the engineer thinks safe. In any case, a loading test can only show the local strength at foundation level, and is of no use at all if softer ground occurs lower down. A striking example of this is illustrated in Fig. 14. The engineers recommended piled foundations, but the owners insisted on a raft. Accordingly, they applied a loading test at foundation level. The ground carried a test load of 2 tons per square foot without appreciable settlement. The raft when built was not loaded to more than ½ ton per square foot, yet very severe settlement took place.

Design of Rafts—General

It frequently happens that the architect does not begin to think of his foundations until he has completed his detailed design of the building. The engineer is then called on to carry a series of widely varying column loads at odd and irregular spacings. If the foundation is known to be soft it assists greatly in the design of the raft if the architect can adopt a fairly close, regular spacing of columns and piers, with the same spacing both ways (say, 20-ft. centres in both directions).

When beginning the design, the engineer should ascertain how much of each column load is dead load, and how much is live load. All dead loads must be well covered, but only a reasonable amount of live load need be provided for.

In deciding on the height of his building the architect must remember that a raft is fairly heavy, and will take up a fair amount of the safe foundation load. A raft for an office building, with columns spaced at about 20-ft. centres both ways, and designed for a foundation pressure of 15 cwt. per square foot, will weigh about 2½ cwt. per square foot, thus leaving only 12½ cwt. per square foot for the superstructure.

If the building weighs 200 lb. per square foot per floor inclusive, it cannot exceed six storeys in height.

Before commencing any reinforced-concrete work a layer of mass concrete 2 in. or 3 in. thick must first be spread over the ground and allowed to harden. The writer does not recommend the alternative of spreading a layer of greaseproof paper instead of mass concrete.

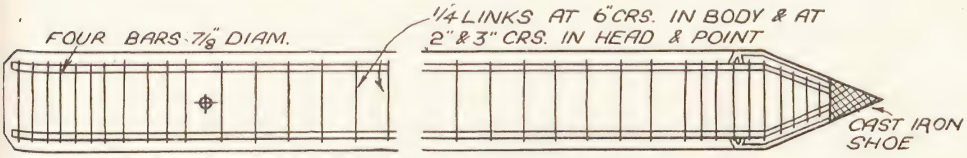
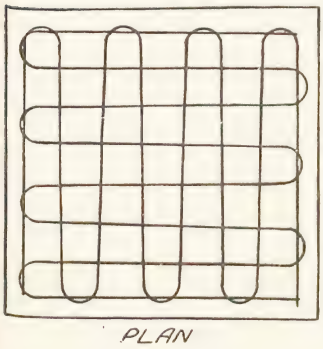


Fig. 20.—14-IN. BY 14-IN. REINFORCED-CONCRETE PILE, 30 FT. LONG



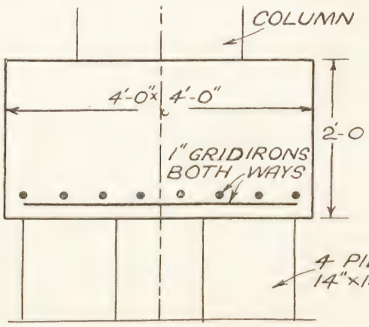


Fig. 21 (*left*).—PILE GROUP TO CARRY 240 TONS

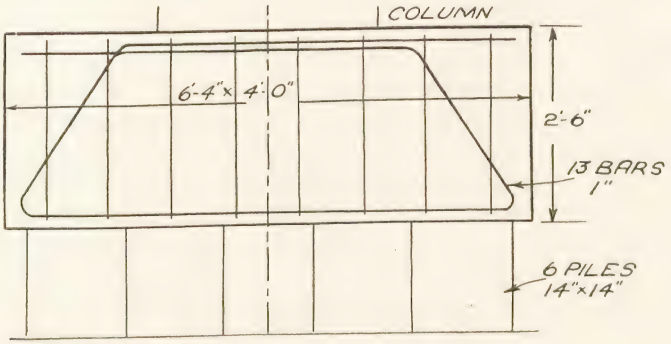


Fig. 22 (*right*).—PILE GROUP TO CARRY 360 TONS

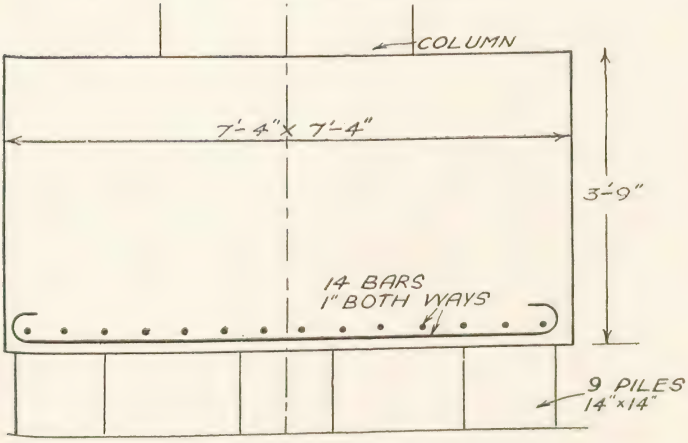


Fig. 23 (*left*).—PILE GROUP TO CARRY 540 TONS

In each cap in Figs. 21, 22 & 23, a different system of reinforcement is shown.

Rafts—Some Examples

The figuring out of a large, complicated, reinforced-concrete raft is a long and difficult process, and must be left to an expert. Speaking generally, a raft with beams in both directions, of the type shown in Figs. 15, 17 to 19, is best for general building work, while flat-slab construction is not very suitable for rafts of any kind except under silos.

It is possible to pass small drainage pipes through the raft beams near mid-span, but any attempt to pass large ducts or sewers at once destroys the strength of the raft in the vicinity. For this reason it is advisable to leave ample clearance between the top of the raft beams and the lowest floor of the building.

Figs. 17 to 19 show a raft for a three-storey shop and office building. The beams are strong enough to carry a load of 2 tons per foot run, while the slab will spread this load uniformly over the site at 6 cwt. per square foot. (The average self-weight of this raft is $1\frac{1}{2}$ cwt. per square foot.) Fig. 15 shows a raft, suitable for a large office building, capable of spreading the stanchion loads over the site at 1 ton per square foot. Fig. 16 shows the reinforcement in a foundation raft for a silo building, where the load is about $2\frac{1}{4}$ tons per square foot.

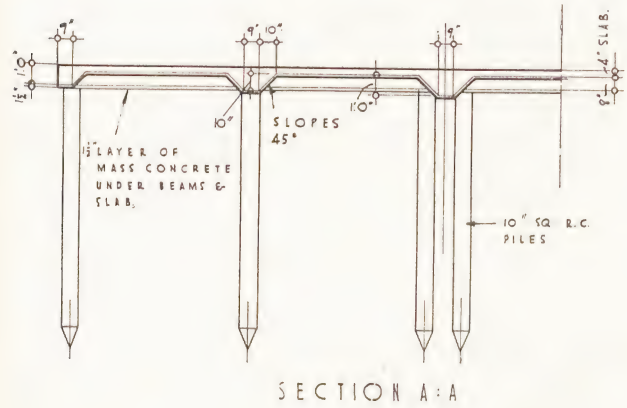
PILED FOUNDATIONS

Ground Movements during Pile Driving

Made-up ground and peat are both compressible, but virgin clay and tightly packed sand are practically incompressible, and driving piles through them causes considerable movements of the ground. A heavy building may weigh 4 tons per square foot on plan. If the piles are loaded to 40 tons per square foot, they will occupy 10 per cent. of the area of the site, and the volume of the piles will be 10 per cent. of the volume of the strata through which they are driven. On one clay site the measured rise of the ground during driving was very closely equal to 100 per cent. of the volume of the piles, but even if we assume that most ground is slightly compressible, we still have to face considerable displacements of the soil. Suppose a heavy building is supported on 1,000 piles, each of which has a volume of 2 cu. yd. The act of driving 2,000 cu. yd. of concrete into the site, even if we assume that the ground will absorb half of this by compression, must displace 1,000 cu. yd. of ground. In general, the displacement will take place upward, but if there are rivers, docks, canals, or other deep cuttings in the vicinity the ground will move laterally into them. On some sites, such as wet sand, the vertical movement is very local, the ground boiling up round each pile ; on others the rise is more widespread.

Some Examples

On a clay site the ground rose locally to a maximum height of 2 ft. 4 in. Setting-out pegs near the pile frame were displaced laterally as



SECTION A:A

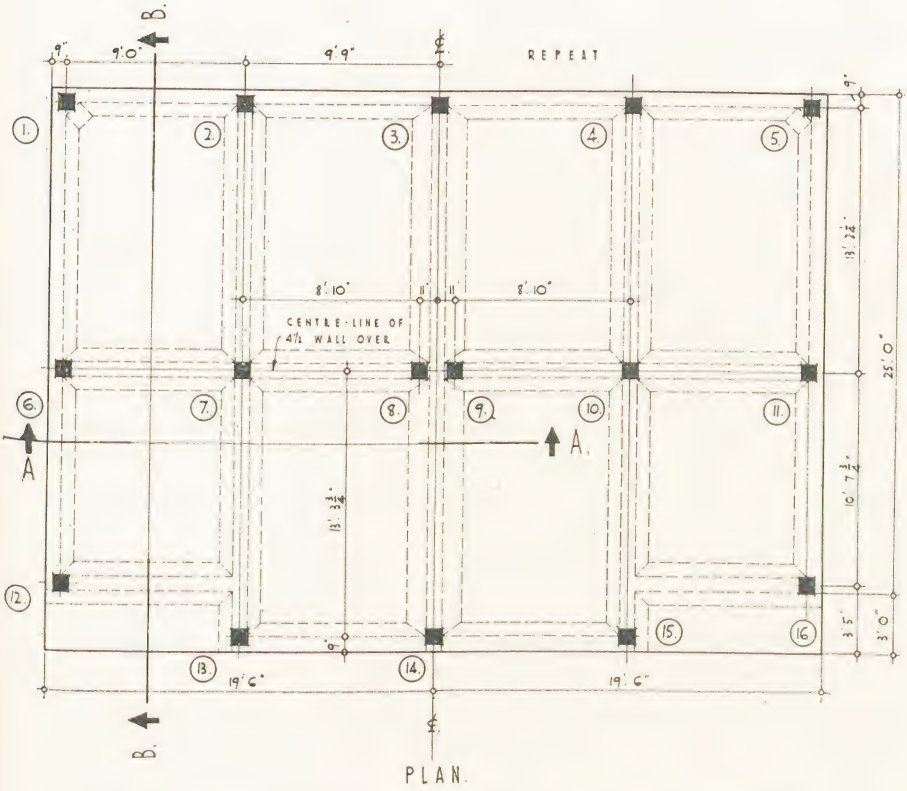


Fig. 24.—PILED FOUNDATIONS FOR PAIR OF SEMI-DETACHED HOUSES
(*Peter Lind & Co. Ltd.*)

much as 12 in. Driving near docks displaced the dock walls bodily; in one case 7 in. and in another 9 in. Driving near a river, despite an open trench down the site, displaced sheet piling and a concrete road behind it by 2½ in. On a confined site some of this lateral movement may be "bottled up" in the form of elastic compression of the ground. Excavating a trench after the piles are all driven will relieve some of the pressure and cause neighbouring piles to move slightly towards the trench.

Vibration due to Driving

In addition to the general displacement of the ground, there is the question of the vibration due to driving causing damage to surrounding property. This vibration is much more superficial and less serious than is generally thought, and may be very much reduced by cutting a trench round the site or by excavating holes and driving groups of piles through the bottom of them.

Bored Piles *versus* Driven Piles

It has been claimed that a bored pile which is sunk to the same depth and into the same stratum as a driven pile will carry the same load. Although on some sites this may be true (as when both piles reach solid rock), on others it is not. A driven pile forms its own foundation by driving down and compressing the ground below it, and the stratum in which the piles find bearing would not support them if it were not for the consolidation it undergoes during the process of pile driving. The writer will not accept bored piles except for light loads, or until several piles on the site have successfully withstood severe loading tests.

Precast *versus* Cast-in-situ Piles

It is doubtful whether there is any system of cast-in-situ piling where the method of placing the concrete is really certain to produce a sound pile on all sites. There is also some doubt as to whether a newly set cast-in-situ pile could safely withstand the vibration and powerful ground movements caused by driving neighbouring piles. It has been claimed that cast-in-situ piling is cheaper than precast piling on a site where the piles vary in length, but the writer's experience does not confirm this.

Timber Piles

If it is absolutely certain that the whole length of every pile is and will always be permanently below ground-water level, then timber piles may be used. The effective life of an Oregon-pine pile in loose ground above ground-water level may be taken as 15 years.

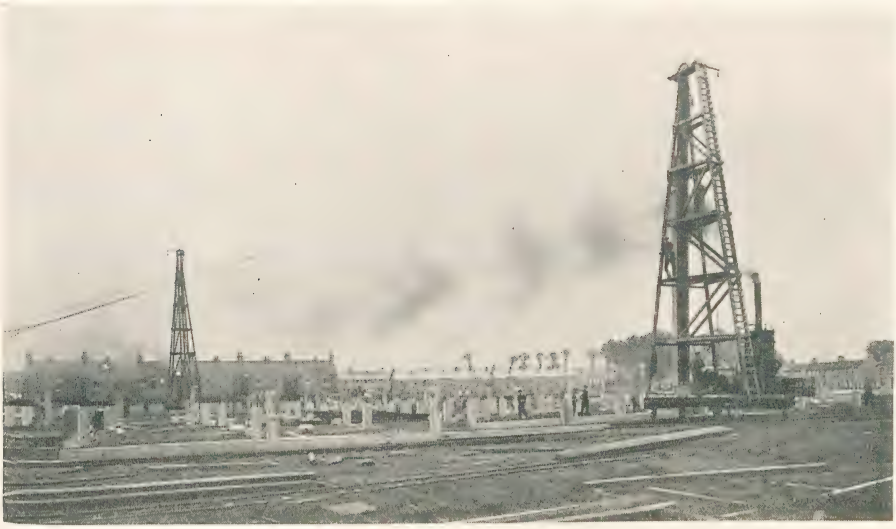


Fig. 25.—PILE FRAMES FOR PILE DRIVING (*Peter Lind & Co. Ltd.*)

Fig. 26.—GROUP OF 14-IN. BY 14-IN. REINFORCED-CONCRETE PILES AFTER HEAVY DRIVING

After being driven, the concrete is cut away from the heads of the piles and the projecting bars are built into the pile caps.

Usual Sizes, Loads, etc.

What may be termed everyday practice in precast piling is as follows :

10-in. by 10-in. section up to 25 ft. long
12-in. by 12-in. ,, ,, ,, 35 ft. ,,
14-in. by 14-in. ,, ,, ,, 40 ft. ,,

These piles are usually driven with drop hammers, of the type in Fig. 25, weighing 30, 40, or 60 cwt., with a fall of 3 ft. to 4 ft., to a set of about 1 in. for 10 blows. When so driven they will safely carry loads of 30, 45, and 60 tons per pile respectively. Longer piles may be 16 in. by 16 in. or 18 in. by 18 in. (either solid or hollow), but special care is necessary in making, handling, and driving long piles, particularly when made of modern rapid-hardening cement.

Discretion is needed when driving into sand, as excavation or pumping on neighbouring sites, or even flow of ground water, may allow the sand to loosen and let the piles through.

A completely isolated group of piles should number not less than three. Groups of one or two piles should be connected by tie-beams to neighbouring groups to eliminate eccentric loading.

On a recent contract, a 16-in. by 16-in. pile 38 ft. long carried a test load of 215 tons for several days. The total vertical settlement (measured by micrometer dial) was $\frac{3}{8}$ in., of which $\frac{1}{4}$ in. was recovered when the load was removed, leaving a permanent settlement of $\frac{1}{8}$ in.

Some Examples

Fig. 20 is a typical detail of a 14-in. by 14-in. precast reinforced-concrete pile. Figures 21, 22, and 23 show groups of 14-in. by 14-in. piles, with suitable pile caps. The group in Fig. 21 will carry 240 tons ; that in Fig. 22 will carry 360 tons, and that in Fig. 23 will carry 540 tons. A different system of reinforcement is shown in each cap. The main point to watch is the grip-length of the bars. The only failure of a cap which the writer has seen was a bond failure.

Although piles are mostly used under heavy buildings, it is sometimes possible to exploit soft ground for housing estates by driving short piles. Fig. 24 shows the foundations of a pair of semi-detached houses. The cost of these, including 15-ft. piles and reinforced-concrete slab and beams, was about £65 per house. A usual type of pile frame is shown in Fig. 25. Some modern frames are mounted on travelling undercarriages which span the site, and the frame moves about in both directions under its own power.

A rough idea of the cost of making and driving reinforced-concrete piles may be obtained by calculating the total volume of concrete in cubic yards. A job with about 200 short 10-in. by 10-in. piles costs about £10 per cubic yard. A job with 1,000 piles, 14-in. by 14-in., of moderate length, costs about £6 per cubic yard.

STRUCTURAL STEELWORK

THE advance in structural design in the last few years has been phenomenal, and it is now possible for the structural steel engineer to meet any specific architectural requirement with the greatest ease. The range of design starts with the simple column and beam types, extends through various triangulated forms of roof construction, either as simple girders or cantilevers, takes in its stride arch forms and, more recently, a variety of portal or frame constructions with singularly attractive æsthetic qualities. Each type, however, must be considered on its merits in relation to the individual case under review.

Steel-frame Building or Reinforced Concrete ?

In steel-frame building and reinforced-concrete methods, both employ steel and both are dependent upon steel for their structural functions. There is a fundamental difference between the two which goes far beyond the initial considerations of quality and cost—a difference of great significance in respect to the financial prospects of any building investment.

The difference between the two techniques is enormous. It starts with the quality of the materials used, determines radically the method of assembly, not only of the carrying structure itself, but of the vast number of component parts that go to make a building. It influences the selection of materials, their combination, and their incorporation in the finished structure.

The steel-frame method represents an open and ordered assembly—a dry technique—and a wide choice of competitive materials, each selected for a particular and definite purpose in the structure. In fact, the method of assembly, important as it is in the initial building operations, is also a measure of its suitability for adaptation throughout its life, its alteration, or its final demolition.

The reinforced-concrete monolithic structure is a constructional method which attempts to solve, by the use of one and the same material, all those varying problems relating to structural strength, weather resistance, appearance, maintenance, and insulation against heat and cold. Economic requirements, such as adaptability and flexibility, together with acoustic considerations, it attempts to satisfy by continuity of structure.

Reinforced concrete cannot effectively satisfy such varied and complicated needs. Like most other building materials, reinforced concrete has distinct economic applications, but the wet processes

involved in its technique are not without important influence on other building components, on subsequent building operations, and on the quality of the finished product. To contend that the shrinkages and workings of a plastic and porous mass from various causes are conducive to good weather resistance, or low maintenance over a period of years, is to turn a blind eye to facts and to court confusion.

Settlements and Movements of Buildings

Unlike steel, which is a ductile material, an inflexible monolithic system is extremely inappropriate for taking up the settlements and movements to which all buildings are subjected. From an acoustic point of view, a rigid homogeneous system which is keyed up tightly produces a series of sound boxes which, unless further expensive counter-measures are employed, result in a most unpleasant structure. Steel-frame construction undoubtedly lends itself much better to acoustic measures.

The monolithic reinforced construction has, not wrongly, been described as the white elephant of modern domestic architecture: it has been carried over from suitable engineering uses and applied to architecture with a complete misconception of the qualities which a habitable building should possess, and with a great disregard of the principles of long-term building finance.

Future of Structural Steelwork

Can there be any doubt as to the future trend of construction? The old brick building had a great deal in its favour. Its disadvantages were that load-carrying brickwork took up a great deal of habitable space, that its foundation problems were more costly, and that it was practically inadaptable to changing needs. As a system of construction —a slow vertical progression—it made for a great deal of labour on the site, and was not conducive to a speedy and predetermined series of operations. It had, however, the great merit of being practically a dry technique, and the materials used had been through the test of time and had produced a habitable combination. Its economic limitations, however, led to the steel-frame technique which, as developed to-day, incorporates the best principles of the older method and has made possible the more easy assembly of a wide range of new materials and new constructions, each better satisfying specific requirements: it has, moreover, opened up a new horizon in planning flexibility.

Steel-frame Constructional Methods

The steel-frame multi-storey constructional method is characterised by a simultaneous vertical and horizontal progression of work rather than by a purely vertical one.

The steel frame is entirely self-supporting and, when used in con-

[*By courtesy of the British Structural Steelwork Association*

STEELWORK AND FINISHED INTERIOR OF BANQUETING HALL, ROYAL INSTITUTE OF BRITISH ARCHITECTS BUILDING, LONDON

[*By courtesy of the British Structural Steelwork Association*

STEELWORK FOR THE MANCHESTER REFERENCE LIBRARY

Showing the dome construction and a portion of the steelwork forming the administration section. The central dome of the building is 127 ft. 6 in. in diameter. This is surrounded by a concentric multi-storey ring, 42 ft. broad, the whole covering a circle of 210 ft. diameter. The main ring was assembled on the floor, lifted in one piece of 14 tons weight, and laid on top of the temporary tower, where it was centred, oriented, and levelled on wedges to keep it about 1 in. high. Erection of dome ribs and multi-storey rings then went on simultaneously until completion.

junction with the new systems of floor construction, presents the lightest type of building. Excessive dead load requires heavy foundations, with a corresponding larger amount of excavation, together with a greater bulk and weight of material to be transported and placed in position, involving increased labour and equipment. Structural steel for the same sectional area is capable of carrying loads many times heavier than is possible with any other material, and leads to an appreciable increase of rentable space.

At comparatively small cost it gives the architect a load-carrying structure which is erected to its full height in a very short time. Its stairways can be completed simultaneously with the frame, providing access everywhere. An incredibly short time elapses before large expanses of horizontal platforms, rising floor upon floor, are made available, upon which the subsequent building operations can proceed in a predetermined and logical sequence.

It is the immense working face, both horizontally and vertically, which is the revolutionary development behind steel, but one which has yet to be fully appreciated and properly evaluated. It represents to building what the "assembly line" represents to efficient motor-car manufacture.

The whole of the building progress is uncluttered, the system gives full and free access everywhere, from the basement to the roof; it gives the architect and the builder a perfect control of the whole complicated series of assembly operations which constitutes modern building methods. The steel, beyond taking care in a clear and precise manner of all the loads, and transmitting them at suitable points to the foundations, is simultaneously a gauge or register for all other components, and even a carrying device for the hoisting and placing of materials and finished components at the right time and in the right place.

A slow vertical progression, whether of brick or reinforced concrete, starts with a forest of scaffolding which interferes with the flow of materials, obscures inspection, hinders every other operation, and leads to a turmoil and confusion of trades.

The vertical construction process is gradually but surely being displaced by the trend of architectural design. The enclosure elements of brick or concrete are now considerably diminished and, in some building types, absolutely superseded by the large areas of metal and glass in windows and stair enclosures.

In consequence, they are assuming quite different proportions and quite different aspects in the bill of costs. Future development is undoubtedly in the direction of dry, shop-fabricated units ready for assembly. Similarly, the internal vertical elements, such as partitions and divisions, are required, from pure financial considerations, to be mobile, and will be chosen, not to conform to a system of casting *in situ*, but to satisfy changing occupational needs.

Steel Erection

The steel-frame method must be envisaged not merely as a structural system, light-and-space-saving, but essentially as a method of assembly.

The steel structure is put in hand and manufactured in advance. When the foundations are sufficiently advanced, the steel erection can begin. Under proper organisation the carrying structure, with its main horizontal elements, such as floor and roof supports, is finished in a remarkably short time. Materials, already thoroughly tested as finished products of industry, are used, and when they arrive on the site no supervision of quality is required. The steel frame is capable immediately of sustaining loads without waiting for lengthy drying out, or setting processes, or 28-day tests ; and provides a suitable platform for the placing of materials required for the subsequent operations.

There are some notable examples in this country where the speed of steel erection has shown good comparison with the best American practice, but it is often evident that the full advantages of steelwork technique have not been properly utilised, through an omission to settle all details well in advance, and to bring to bear upon the foundation work the same efficiency which characterises the framework erection.

Floors and Roofs

With the completion of the steelwork, the laying of floors and roofs becomes a simple process. Here again, with adequate forethought, these elements can be completed without any appreciable time-lag and, it must be emphasised, without any sacrifice of quality on the site. Speed emerges not from any hurried preparation of material on the site, or the massing of labour and machines, but purely from a logical method of fitting all prefabricated units into the building. A perfectly dry technique is achieved, unhindered by weather, and providing immediate shelter to the workman.

It transpires, unfortunately too often, that floor construction does not keep pace with the steel, and full efficiency is lost by not maintaining floor construction up to the speeds obtained by the steelwork erector.

It is obvious, however, that where a rational flow of work is devised, it must lead to considerable cost reduction over other methods, with which such a clear series of operations is not possible. The magnitude of this becomes apparent when it is remembered that the floor and roof constructions themselves are not only important items in the total bill of costs, but by offering large areas which constitute working platforms, they provide the basis of cost reduction and quality work in almost every other element of the building.

Plumbing and Piping

So far consideration has been given to the vertical supporting elements, the simplification of foundations by light point loading, and the large

working faces exposed to simultaneous "attack" in the assembly. There may now be examined the effect of this mechanised performance on other operations. Consider, for example, those vertical components which are often the cause of the greatest despair—plumbing and piping.

Full preparations having been made, the plumbing and other services can follow the steel and the floors. Units manufactured under workshop conditions can be brought to the site, and the drainage, gas, water, and electricity main services can follow in the proper sequence, and be completed to a stage that leaves fittings to be attached at a later period of the assembly.

The "making-good," and the hundred-and-one contingencies which are wont to appear in the balance-sheet of costs, should have as little place in building as they have in other industrialised operations of assembly; "making good" in competitive motor-car manufacture would drive makers into the bankruptcy court.

Exterior and Interior Fillings

How does the steel frame influence the other vertical items of enclosures and partitions? Firstly, it permits the widest selection of materials, steel and glass, bricks and hollow blocks, and insulating materials behind a weather-resisting outer wall. The utmost latitude remains to the architect, and whatever his choice the steel frame gives an accurate "register" which enables him to design, and have ready for assembly, units which can take their place as works of quality and precision carried out in specialised manufacturing establishments.

It is often said that building costs in America are the same as in this country despite the higher labour charges. This can be explained only by the more highly-developed organisation of site work, and the utmost use of cost-reducing factors inherent in the steel frame.

The developments and variety which industries are offering to architects in the quality, colour, and surface finish of their products, combining appearance and fitness with low maintenance, will prove to be more valuable used with steel-frame construction than with any other method of building.

In commercial architecture, especially of the multi-storey type of building, economic forces are now a compelling influence on design, and there is everywhere to be observed a tendency towards greater standardisation.

In other branches of industry, standardisation has led to a progressive reduction of cost and a progressive improvement in quality. The newer products, such as the motor-car, the motor-coach, and the aeroplane, have developed qualities and æsthetics of their own.

In the steel-frame constructional method, the load-carrying problems are dealt with distinctly and without any confusion between structural and filling elements. Within its register, the steel frame promotes the

easy assembly of sheet-metal window surrounds, steel door frames, and steel trim. Both exterior and interior filling elements can be easily attached. The day is not far distant when these will be produced in dry full-length slabs, and even cellular sheet-steel floor units, giving a 100 per cent. dry assembly and a perfect electrical conduit system, will be available.

The subject of acoustics is too involved to enter upon here, but it is well known that the contact of dissimilar materials of varying acoustic properties leads to the damping down of sound waves, and that, in consequence, the articulated nature of the steel-frame building presents greater possibilities for noise reduction than the monolithic reinforced-concrete type, with its series of interconnected diaphragms. As the science of acoustic design progresses, the steel frame will be found to offer the best possibility of a succession of acoustic "breaks." Indeed, the selection of the filling materials and their relation one to the other, with cleavages for sound absorption or sound reflection, will largely be determined by this factor, rather than by any consideration of structure-continuity, which is equivalent to noise continuity.

Financial Considerations

It is not necessary here to go into the many factors which bring about an early obsolescence. It is clear that recent ideas about the length of the earning-life of buildings have undergone a most pronounced change. In the past, architects thought they could build for posterity—the general mass of our commercial and domestic architecture proves the contrary to-day. We have definitely reached a phase in which it is impossible to look beyond the requirements of our own generation.

It is in consequence essential that our buildings be assembled with a view to change, not only internally but externally as well.

To safeguard an investment in a building one must, therefore, be sure that the building has future value built into it. If the construction follows the steel-frame technique, the income can be maintained by simple adaptation as long as possible, and then, when it is obsolete and a new building is required, the least expense and time will be incurred in clearing the site, and not only the steel but many of the other components will be salvaged.

A reinforced-concrete type of construction is one in which changes and alterations are difficult and costly, if not impossible. There has been very limited experience of this in this country, but from failures which have been demolished with pneumatic hammer and drill the process has proved both inconvenient and costly.

Obsolescence and its economic relation to the type of building construction is a matter now receiving the increased attention of building owners, who naturally consider the security of their money ; it is a matter which definitely figures in the balance-sheet of costs.

[*By courtesy of the British Structural Steelwork Association*

BUS GARAGE AT NORWICH

This garage has a clear span of 171 ft. and a width of 240 ft. The unobstructed floor space provides the utmost facilities for manœuvring the buses. Roofs show 6 lattice girders 171 ft. long, weighing 25 tons each, supporting 78 umbrella-type trusses and cambered to provide the large fall necessary for the valley gutters.

Building Regulations

The present development of steel-frame technique has been partly determined by traditional concepts and partly by building regulations. In fact, building regulations have done as much to perpetuate traditional ideas as anything else, but a greater freedom is fortunately in sight.

Fire Resistance

The fire-encasement of steel—prescribing thickness rather than fire-resisting qualities—has led to unnecessary expense. The steel in a concrete member is required to have much less encasement than that in a structural column which, by its size, can transmit the heat at a much more rapid rate. But when the fire-resistant materials have been examined more closely it will be possible to effect greater economies and, at the same time, to use materials which will perform the dual function of resisting fire and of giving better acoustic properties : with the present handicaps removed, steel will show to still better advantage. If we apply the criterion of weight of construction for " pay load," the ordinary building compares abominably with the aeroplane or the motor-coach.

Whatever aspect of design is considered—floors, walls, encasement—we discern the restraining hand of authority and the dead weight of tradition. No other major industry has been so hedged in with restrictive influences. Nevertheless, mild steel has a noteworthy period of development behind it, and we are now entering upon a new age in steel construction.

Welded Work

The extreme adaptability of the steel structure is being further increased by remarkable developments in welding, and in future the steel type can be altered, strengthened, and adapted to almost any requirement of the building owner with the least interference to the occupants, without serious loss of business, and with the least expense. Already, welding has enabled existing structures to be modified to new uses by the most simple expedients.

New Steels and New Architectural Forms

From the metallurgical side there are now available the new high-tensile steels capable of carrying 50 per cent. greater stress than the ordinary mild steel ; the ultimate influence of this material on architectural design cannot be exaggerated. The already slender proportions of steelwork, and the weight on foundations, will be further reduced, and clear spans increased : the new steel will inspire new architectural

forms. Depths of constructional members will be lessened, leading to cost reduction in other quarters, and a greater usable space.

All constructional work is the economic bridging of space, and it is a stimulating reflection to turn from those buildings like the old Crystal Palace, and some of the 100-year-old railway die-hards, and to picture what this new material, undreamt of by our predecessors, has in store for us when we really emerge from the Victorian era and turn to grapple with the great problem of Building's future.

The age of steel construction, under a new freedom, will acquire a new predominance. The sheet-steel technique of the motor-car will find its place in the hitherto conservative preserves of building. Steel sheet with new plastic finishes will be available, giving perfect weather-resistance and high decorative qualities.

The hiatus between the architect and engineer, which at present is the outcome of a transitional phase, will disappear. Building will become an art of assembly not tied to traditional materials and forms, but mobilising the whole resources of industry, building into the steel frame a great variety of products fashioned with meticulous care, products yielding a variety of colour, texture, and form—each a co-ordinated part of a modern conception, but, above all, with æsthetic and physical properties which expressly suit their varying functions.

Technical Data and Formulæ

BRITISH STANDARD SECTIONS FOR BEAMS

Uniformly Distributed Loads in Tons

The tabulated loads on the following pages are based on extreme fibre, tensile, and compressive stresses of 8 tons per square inch, corresponding to 17,920 lb. per square inch.

THE TON....is the long ton of 2,240 lb.

L = length of effective span in feet.

f = stress, extreme fibre, tensile, or compressive, in tons or lb. per square inch.

W = weight or load uniformly distributed in tons or lb.

Z = modulus of the section in inches^3, relative to axis $x-x$.

$$W = \frac{8f.Z}{12L} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

W and f being in the same units.

Each tabulated load includes the weight of the section and implies uniform distribution of the load over the entire length of the effective span.

Each beam is assumed to have its ends simply supported, and to be stayed laterally at distances not exceeding twenty times the flange breadth.

All loads are static loads.

Deflection

d = depth of beam in inches.
δ = deflection at centre of span in inches.
E = elastic modulus, 13,000 tons per square inch.
J = moment of inertia in inches^4.
l = length of span in inches.
L = length of span in feet.
f = stress, extreme fibre, in tons per square inch.
W = weight or load, uniformly distributed, in tons.
Z = modulus of section in inches^3.

$$\delta = \frac{5}{384} \cdot \frac{W \cdot l^3}{E \cdot J} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$W = \frac{8f \cdot Z}{12L} \text{ (1) and } J = \frac{d}{2} Z \quad . \quad . \quad . \quad . \quad (3)$$

In (2), substitute (1) for W ; (3) for J ; $(12L)^3$ for l^3, and cancel, then—

$$\delta = \frac{3f \cdot L^2}{1300d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

For $f = 8$ tons per square inch, $\delta = \frac{24L^2}{1300d}$ . . . . . (5)

Deflection Coefficient

The tabulated deflection coefficient is equal to :—

$$\frac{24}{1300d} \text{ for 8 tons per square inch.}$$

Then $\delta = K \cdot L^2$ for the tabular loads. K being the deflection coefficient . . . . . (6)

Zigzag Lines

The zigzag lines indicate the limiting spans beyond which the calculated deflections will exceed $\frac{1}{325}$th of the span for beams supporting the tabular loads.

Web Buckling

The undernoted formulæ give limiting maximum loads and minimum spans. For greater loads on lesser spans, stiffeners may be required to prevent web buckling.

Aw = area of beam web, net, in square inches = $d\omega \cdot t\omega$. (7)
bs = buckling stress in tons per square inch of net web area

$$= 5{\cdot}5 - 0{\cdot}04 \frac{d\omega}{t\omega} \text{ for } f \text{ of 8 tons per square inch} \quad . \quad . \quad (8)$$

$d\omega$ = depth of beam web, net, in inches.
f = extreme fibre stress in tons per square inch.
$L_{min.}$ = length of span, minimum, in feet, corresponding to $W_{max.}$

W = weight, load, or reaction, maximum, in tons, concentrated at any point of the span.
$W_{max.}$ = weight or load in tons, maximum, uniformly distributed.
W_F = weight or load in tons uniformly distributed over a span of 1 ft.
$t\omega$ = thickness of beam web in inches.

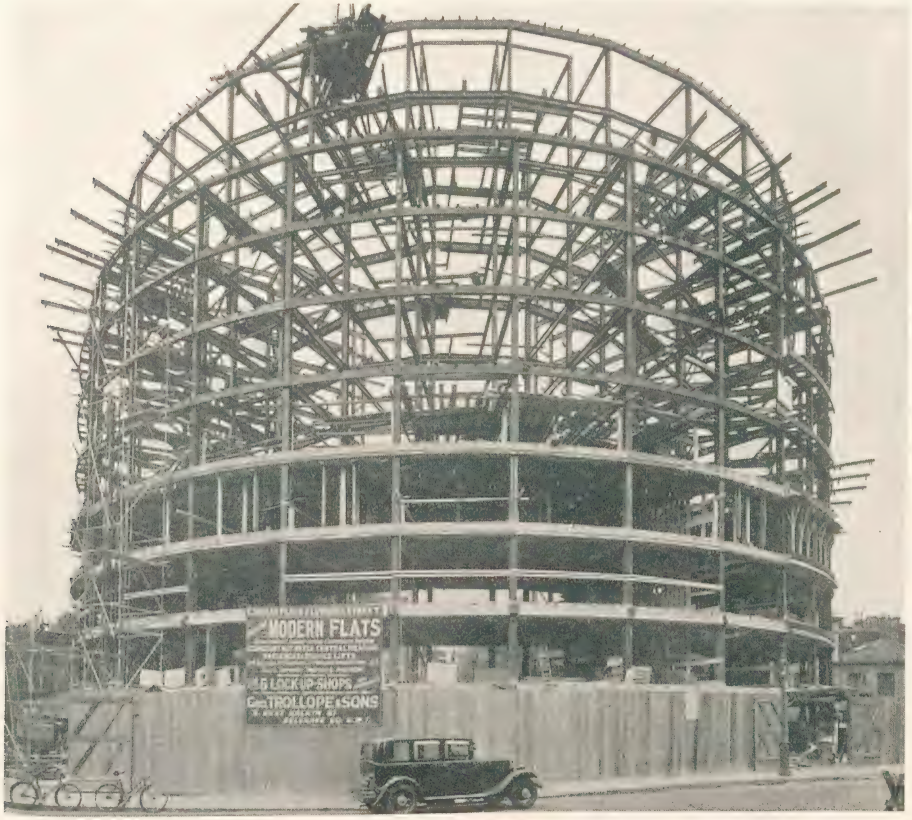
$$W = Aw \cdot bs \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$W_{max.} = 2W \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$L_{min.} = \frac{W_F}{W_{max.}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Dotted Lines

The limits of maximum loads and minimum spans are indicated on the tables of loads, where they occur, by means of dotted lines.



[By courtesy of the British Structural Steelwork Association

STRUCTURAL STEELWORK FOR A BLOCK OF MODERN LUXURY FLATS IN LOWNDES STREET, LONDON, S.W.1

BRITISH STANDARD SECTIONS FOR BEAMS

UNIFORMLY DISTRIBUTED LOADS IN TONS BASED ON AN EXTREME FIBRE STRESS OF 8 TONS PER SQUARE INCH

Size	*Approx. Weight per Foot*	*Spans in Feet*												*Deflection Coefficients*
		3	4	5	6	7	8	9	10	11	12	14	16	
in. *in.*	*lb.*													
3 × 1½	4	1·9	1·4	1·1	0·9	0·8	0·7							0·006154
3 × 3	8·5	4·5	3·3	2·7	2·2	1·9	1·6							0·006154
4 × 1¾	5	3·2	2·4	1·9	1·6	1·3	1·2	1·0	0 9					0·004615
4 × 3	10	6·9	5·1	4·1	3·4	2·9	2·5	2·3	2·0					0·004615
4¾ × 1¾	6·5	5·0	3·7	3·0	2·5	2·1	1·8	1·6	1·5	1·3				0·003886
5 × 3	11		7·2	5·8	4·8	4·1	3·6	3·2	2·9	2·6	2·4			0·003692
5 × 4½	20		13·3	10·6	8·8	7·6	6·6	5·9	5·3	4·8	4·4			0·003692
6 × 3	12		9·3	7·4	6·2	5·3	4·6	4·1	3·7	3·3	3·1	2·6	2·3	0·003077

Tabular loads to right of full zigzag line produce deflection greater than $\frac{1}{325}$th of the span.
Tabular loads to left of dotted line are beyond web-buckling limits as calculated by formulæ.
Let δ = deflection in inches, K = deflection coefficient, and L = span in feet ; then $\delta = K . L^2$.
Spans are effective spans between centres of bearings. Ends of beams are simply supported.

BRITISH STANDARD SECTIONS FOR STEEL BEAMS

UNIFORMLY DISTRIBUTED LOADS IN TONS BASED ON AN EXTREME FIBRE STRESS OF 8 TONS PER SQUARE INCH

Size	*Approx. Weight per Foot*	*Spans in Feet*													*Deflection Coefficients*
		4	5	6	7	8	9	10	12	14	16	18	20	22	
in. in.	*lb.*														
6 × 4½	20	15·4	12·3	10·2	8·8	7·7	6·8	6·1	5·1	4·4	3·8				0·003077
6 × 5	25	19·4	15·5	12·9	11·0	9·7	8·6	7·7	6·4	5·5	4·8				0·003077
7 × 4	16		12·0	10·0	8·6	7·5	6·6	6·0	5·0	4·3	3·7	3·3			0·002637
8 × 4	18		14·8	12·3	10·5	9·2	8·2	7·4	6·1	5·2	4·6	4·1	3·7		0·002307
8 × 5	28		23·9	19·9	17·0	14·9	13·2	11·9	9·9	8·5	7·4	6·6	5·9		0·002307
8 × 6	35		30·6	25·5	21·9	19·1	17·0	15·3	12·7	10·9	9·5	8·5	7·6		0·002307
9 × 4	21		19·2	16·0	13·7	12·0	10·6	9·6	8·0	6·8	6·0	5·3	4·8	4·3	0·002051
9 × 7	50					30·8	27·4	24·6	20·5	17·6	15·4	13·7	12·3	11·2	0·002051

Tabular loads to right of full zigzag line produce deflection greater than $\frac{1}{325}$th of the span.
Tabular loads to left of dotted line are beyond web-buckling limits as calculated by formulæ.
Let δ = deflection in inches, K = deflection coefficient, and L = span in feet ; then $\delta = K . L^2$.
Spans are effective spans between centres of bearings. Ends of beams are simply supported.

BRITISH STANDARD SECTIONS FOR STEEL BEAMS

UNIFORMLY DISTRIBUTED LOADS IN TONS BASED ON AN EXTREME FIBRE STRESS OF 8 TONS PER SQUARE INCH

Size	*Approx. Weight per Foot*	*Spans in Feet*														*Deflection Coefficients*
		6	7	8	9	10	12	14	16	18	20	22	24	26	28	
in. in.	*lb.*															
10 × 4½	25	21·7	18·6	16·3	14·4	13·0	10·8	9·3	8·1	7·2	6·5	5·9	5·4			0·001846
10 × 5	30	26·0	22·2	19·4	17·3	15·6	12·9	11·1	9·7	8·6	7·8	7·0	6·5			0·001846
10 × 6	40		31·2	27·3	24·2	21·8	18·2	15·6	13·6	12·1	10·9	9·9	9·1			0·001846
10 × 8	55				34·2	30·7	25·6	21·9	19·2	17·1	15·3	13·9	12·8			0·001846
12 × 5	32					19·6	16·3	14·0	12·2	10·9	9·8	8·9	8·1	7·5	7·0	0·001538
12 × 6	44					28·1	23·4	20·1	17·5	15·6	14·0	12·7	11·7	10·8	10·0	0·001538
12 × 6	54					33·4	27·8	23·8	20·8	18·5	16·7	15·1	13·9	12·8	11·9	0·001538
12 × 8	65					43·3	36·1	30·9	27·0	24·0	21·6	19·7	18·0	16·6	15·4	0·001538

Tabular loads to right of full zigzag line produce deflection greater than $\frac{1}{325}$th of the span.
Tabular loads to left of dotted line are beyond web-buckling limits as calculated by formulæ.
Let δ = deflection in inches, K = deflection coefficient, and L = span in feet ; then $\delta = K . L^2$.
Spans are effective spans between centres of bearings. Ends of beams are simply supported.

BRITISH STANDARD SECTIONS FOR STEEL BEAMS

UNIFORMLY DISTRIBUTED LOADS IN TONS BASED ON AN EXTREME FIBRE STRESS OF 8 TONS PER SQUARE INCH

Size	*Approx. Weight per Foot*	*Spans in Feet*														*Deflection Coefficients*
		10	12	14	16	18	20	22	24	26	28	30	32	36	40	
in. in.	*lb.*															
13 × 5	35	23·2	19·3	16·6	14·5	12·9	11·6	10·5	9·6	8·9	8·3	7·7				0·001420
14 × 6	46	33·7	28·0	24·0	21·0	18·7	16·8	15·3	14·0	12·9	12·0	11·2	10·5			0·001318
14 × 6	57	40·6	33·8	29·0	25·3	22·5	20·3	18·4	16·9	15·6	14·5	13·5	12·6			0·001318
14 × 8	70	53·7	44·7	38·3	33·5	29·8	26·8	24·4	22·3	20·6	19·1	17·9	16·7			0·001318
15 × 5	42	30·4	25·3	21·7	19·0	16·9	15·2	13·8	12·6	11·7	10·8	10·1	9·5	8·4		0·001230
15 × 6	45	34·9	29·1	24·9	21·8	19·4	17·4	15·9	14·5	13·4	12·4	11·6	10·9	9·7		0·001230
16 × 6	50	41·2	34·3	29·4	25·7	22·8	20·6	18·7	17·1	15·8	14·7	13·7	12·8	11·4	10·3	0·001153
16 × 6	62	48·3	40·2	34·5	30·2	26·8	24·1	21·9	20·1	18·5	17·2	16·1	15·1	13·4	12·0	0·001153

Tabular loads to right of full zigzag line produce deflection greater than $\frac{1}{325}$th of the span.
Tabular loads to left of dotted line are beyond web-buckling limits as calculated by formulæ.
Let δ = deflection in inches, K = deflection coefficient, and L = span in feet ; then $\delta = K . L^2$.
Spans are effective spans between centres of bearings. Ends of beams are simply supported.

BRITISH STANDARD SECTIONS FOR STEEL BEAMS

UNIFORMLY DISTRIBUTED LOADS IN TONS BASED ON AN EXTREME FIBRE STRESS OF 8 TONS PER SQUARE INCH

Size	*Approx. Weight per Foot*	*Spans in Feet*													*Deflection Coefficients*
		10	12	14	16	18	20	22	24	26	28	30	32	36	40	
in. *in.*	*lb.*															
16 × 8	75	64·9	54·1	46·3	40·5	36·0	32·4	29·5	27·0	24·9	23·1	21·6	20·2	18·0	16·2	0·001153
18 × 6	55	49·8	41·5	35·6	31·1	27·7	24·9	22·6	20·7	19·1	17·8	16·6	15·5	13·8	12·4	0·001025
18 × 7	75	68·2	56·8	48·7	42·6	37·8	34·1	31·0	28·4	26·2	24·3	22·7	21·3	18·9	17·0	0·001025
18 × 8	80	76·5	63·8	54·6	47·8	42·5	38·2	34·8	31·9	29·4	27·3	25·5	23·9	21·2	19·1	0·001025
20 × 6½	65	65·3	54·4	46·7	40·8	36·3	32·6	29·7	27·2	25·1	23·3	21·7	20·4	18·1	16·3	0·000923
20 × 7½	89	89·2	74·3	63·7	55·7	49·5	44·6	40·5	37·1	34·3	31·8	29·7	27·8	24·7	22·3	0·000923
22 × 7	75	81·2	67·7	58·0	58·0	45·1	40·6	36·9	33·8	31·2	29·0	27·0	25·4	22·5	20·3	0·000839
24 × 7½	95	112·5	93·8	80·4	70·3	62·5	56·2	51·1	46·9	43·2	40·2	37·5	35·1	31·2	28·1	0·000769

Tabular loads to right of full zigzag line produce deflection greater than $\frac{1}{325}$th of the span.
Tabular loads to left of dotted line are beyond web-buckling limits as calculated by formulæ.
Let δ = deflection in inches, K = deflection coefficient, and L = span in feet ; then $\delta = \mathrm{K.L^2}$.
Spans are effective spans between centres of bearings. Ends of beams are simply supported.

REINFORCED CONCRETE

OUTLINE OF THEORY AND REGULATIONS CONTROLLING DESIGN AND CONSTRUCTION

IT is more than thirty years since reinforced concrete was first used in this country, and during that comparatively brief space of time it has steadily advanced to a leading position among the materials of construction.

The mathematical theories on which reinforced concrete design is based have proved to be justified, for whilst they are not truly representative of what occurs in the actual structures, they give results which are safe and economical. Though certain factors are often ignored (for instance, shrinkage of concrete on setting, "flow" of concrete, and movement of concrete due to moisture), the structures produced are quite capable of carrying their loads, and it would appear that some kind of adjustment takes place which allows high local stresses to be relieved. This adjustment is not, of course, peculiar to concrete : but the matter is mentioned because the student is apt to regard his calculations (often long and needlessly accurate in an arithmetical sense) as symbolical of what happens in the structure itself.

Necessity for Reinforcement

Good concrete is strong in compression, but comparatively weak in tension. Therefore steel, which is much stronger in tension, is introduced to help the concrete. In a freely supported beam, for instance, steel is put in the bottom to take care of the tensile stresses. Thus we get a composite beam, where the concrete takes compression and the steel takes tension. This is an elementary explanation, but, in general, it applies throughout reinforced-concrete work. If there is compression, let concrete take it ; sometimes, however, steel is added for various reasons. If there is tension, let steel take it, although, to some extent, the concrete and the steel will actually act together. Steel is not used alone for compression. Concrete is not used alone for tension.

Code of Practice

Since the War there has been a growing demand for classification, revision, and some measure of standardisation in reinforced concrete design, and as a result of this the Building Research Board of the Department of Scientific and Industrial Research appointed a Committee to make

TABLE I.—PERMISSIBLE STEEL STRESSES

Loading of Member	*Type of Stress in Steel*	*Permissible Stress Lb. per Sq. In.*	
		Mild Steel complying with B.S.S. No. 15	*Mild Steel complying with B.S.S. No. 15, and with a Yield-point Stress of not less than 44,000 lb. per sq in.*
Bending .	Tension in longitudinal steel in beams, slabs, or columns subject to bending	18,000	20,000
	Compression in longitudinal steel in beams, slabs, or columns subject to bending where the compressive resistance of the concrete is taken into account	The compression stress in the surrounding concrete multiplied by the modular ratio	
	Compression in longitudinal steel in beams where the compressive resistance of the concrete is not taken into account	18,000	20,000
Direct Compression	Compression in longitudinal steel in axially loaded columns	13,500	15,000
	Tension in spiral reinforcement . .	13,500	15,000
Shear . .	Tension in web reinforcement . .	18,000	18,000

recommendations for rules of practice. The report of this Committee was issued in January 1934 as *Recommendations for a Code of Practice for the Use of Reinforced Concrete in Buildings*. For convenience it is usually referred to as the "Code of Practice," or, where the meaning is implied by the context, merely as the "Code." Copies may be obtained from H.M. Stationery Office, Adastral House, Kingsway, London, W.C.2.

STEEL

Elasticity

Until the elastic limit is reached the stress-strain curve for steel is a straight line, indicating that the stress is proportional to the strain. Beyond the elastic limit the strains increase rapidly for small increases of stress, until at the yield-point there is a sudden increase in strain without any additional load being applied. It will be clear that as soon as the yield-point is reached the steel will stretch considerably, and thus throw great stress on the concrete, resulting in the formation of cracks. It may be assumed, then, that this is the useful limiting stress for the steel.

Let t = tensile stress in steel.
e = strain.
Es = elastic modulus (or modulus of elasticity) of steel.

$$Es = \frac{t}{e} = 30{,}000{,}000 \text{ lb. per square inch for mild steel.}$$

Working Stresses

The stresses in the steel should not exceed those given in Table I. In solid slabs other than flat slabs, subject to bending, the stress for approved hard-drawn steel wire may be increased up to a value equal to 0·45 of the yield-point stress, but not exceeding 25,000 lb. per square inch, providing that the area of steel in tension does not exceed 1 per cent. of the effective area of the slab.

TABLE II.—REQUIREMENTS FOR THE THREE GRADES

Requirements	*Ordinary Grade*	*High Grade*	*Special Grade*
Preliminary tests (before commencement of job)	Made when required by designer.	To be made unless other evidence of required strength is produced.	As high grade.
Work tests :	—		
(*a*) Strength		(*a*) Two cubes weekly, and when materials or mixes are changed.	(*a*) Two cubes twice weekly, and when materials are changed.
(*b*) Consistence (slump test)		(*b*) Daily.	(*b*) Daily.
Supervision .	—	Competent foreman and qualified responsible supervisor or clerk of works.	As high grade.
Water content and consistence	Slump not to exceed 6 in.	As ordinary grade.	As ordinary grade. Water-cement ratio not to exceed preliminary test figure by more than 10 per cent.
Cement . .	To be measured by weight.	As ordinary grade.	As ordinary grade. Special provision for uniform supply.
Grading of aggregates	—	—	Controlled to agree with preliminary tests.
Type of calculations	—	—	Structure to be designed as monolithic framework.

CONCRETE

Working Stresses

The Code recognises three grades of concrete : ordinary grade, high grade, and special grade. Requirements for the three grades are given in Table II. Minimum cube strengths, permissible stresses, and modular ratios are given in Table III. Details of cube tests for controlling the quality of the concrete are given in the appendices to the Code.

TABLE III.—CONCRETE STRESSES

Mix Reference	*Nominal Mix*	*Proportions : Cu. ft. of Aggregate per 112-lb. bag of Cement*		*Minimum Cube Strength Requirements at 28 days, in Lb. per Sq. In.*		*Modular Ratio* m.	*Permissible Concrete Stresses in Lb. per Sq. In.*			
		Fine	*Coarse*	*Prelim. Test*	*Works Test*		*Bending*	*Direct*	*Shear*	*Bond*
Ordinary-grade Concrete				$4{\cdot}5x$	$3x$	$\frac{40{,}000}{3x}$	x	$0{\cdot}8x$	$0{\cdot}1x$	$0{\cdot}1x+25$
I	1 : 1 : 2	$1\frac{1}{4}$	$2\frac{1}{2}$	4328	2925	14	975	780	98	123
II	1 : 1·2 : 2·4	$1\frac{1}{2}$	3	4163	2775	14	925	740	93	118
III	1 : 1·5 : 3	$1\frac{7}{8}$	$3\frac{3}{4}$	3825	2550	16	850	680	85	110
IV	1 : 2 : 4	$2\frac{1}{2}$	5	3375	2250	18	750	600	75	100
High-grade Concrete				$4{\cdot}5x$	$3x$	$\frac{40{,}000}{3x}$	x	$0{\cdot}8x$	$0{\cdot}1x$	$0{\cdot}1x+25$
I	1 : 1 : 2	$1\frac{1}{4}$	$2\frac{1}{2}$	5625	3750	11	1250	1000	125	150
II	1 : 1·2 : 2·4	$1\frac{1}{2}$	3	5400	3600	11	1200	960	120	145
III	1 : 1·5 : 3	$1\frac{7}{8}$	$3\frac{3}{4}$	4950	3300	12	1100	880	110	135
IV	1 : 2 : 4	$2\frac{1}{2}$	5	4275	2850	14	950	760	95	120
Special-grade Concrete				$5x$	$3x$	$\frac{40{,}000}{3x}$	x	$0{\cdot}8x$	$0{\cdot}1x$ but not greater than 150	$0{\cdot}1x+25$ but not greater than 150
I	1 : 1 : 2	$1\frac{1}{4}$	$2\frac{1}{2}$	Strength requirements, modular ratios, and permissible stresses to be calculated from the above factors, and to be based on preliminary test results. The values for the permissible stresses shall not exceed those for similar mixes of high-grade concrete by more than 25 per cent. Shear and bond stresses shall not exceed 150 lb. per square inch.						
II	1 : 1·2 : 2·4	$1\frac{1}{2}$	3							
III	1 : 1·5 : 3	$1\frac{7}{8}$	$3\frac{3}{4}$							
IV	1 : 2 : 4	$2\frac{1}{2}$	5							

Where other proportions of fine to coarse aggregate are used the requirements shall be based on the ratio of the sum of the volumes of the fine and coarse aggregates, each measured separately, to the quantity of cement, and shall be obtained by proportion from the two nearest defined mixes. Exact values for modular ratio may be used, calculated from the formula $\frac{40{,}000}{3x}$.

Dimensional Changes

Dimensional changes in concrete are due to four causes :—

(1) Shrinkage.
(2) Moisture.
(3) Load, including time effect.
(4) Temperature.

Change will occur in a concrete whatever its age if any one of the last three factors should vary : and shrinkage appears to go on indefinitely, other things remaining constant, although at later periods its effect is probably slight. Set cements change their volume with variations in moisture conditions in the same way as clays and mortars, and concretes are affected similarly. These dimensional changes occur not only immediately after setting, but throughout the life of a specimen so long as it is capable of absorbing and giving up moisture. Dimensional changes due to causes other than temperature have been known to exist for some time, and many research workers have reported results of tests showing shrinkage in air and expansion in water.

Quite apart from the volume changes due to moisture are those caused by variations in temperature. Concrete, like other structural materials, expands when heated and shrinks on cooling.

When concrete is subjected to stress there is a corresponding strain. Immediately after the load is applied the whole of the strain may be considered as " elastic deformation," but under a sustained load it will be found that there is a further movement known as " plastic deformation." This property possessed by concrete of yielding very gradually under a sustained load is quite distinct from the shrinkage caused by the release of uncombined water when concrete is cured in air. It follows, therefore, that the stress-strain relation varies with the stress and also with the time during which the stress has operated. This yielding is now generally known as " creep " or " flow."

Concrete cured in air will shrink, say, about $\frac{1}{2}$ in. in 100 ft. If the concrete is reinforced, the steel will resist the shortening, so that in an unrestrained structure compressive stresses are developed in the steel and tensile stresses are set up in the concrete. Shrinkage cracks can be minimised or prevented by providing adequate steel and/or joints.

These stresses, set up in both concrete and steel, are allowed for in design by the use of suitable basic values (for the modular ratio, for instance) and the exercise of common sense. In the larger structures special calculations are frequently made.

REINFORCED CONCRETE

Modular Ratio

To avoid repetition, and to allow the tables to be compact, reference has already been made to the modular ratio, the name given to

the ratio $\frac{\text{Elastic modulus of steel}}{\text{Elastic modulus of concrete}} = \frac{Es}{Ec} = m.$

We have already seen that the elastic modulus of steel can be determined, but with concrete the case is quite different. For instance, the ratio of stress to strain is not constant. Again, the ratio varies with age. If we assume a value of 2,000,000 lb. per square inch, the value of m becomes 15, and this figure has been used for design purposes in this country for many years. Reference to Table III will show that varying values of m are given in the Code, as it has been found that these figures give satisfactory results in practice. Without going into the matter further we must accept the fact that it is safe to use values of the modular ratios that are higher than the true values. For instance, the true modular ratio for 4 : 2 : 1 concrete may be 10, but the value used for design purposes may be 18. Owing to the effect of creep, the stress in the steel gradually increases, while that in the concrete decreases. By using a higher value for m the designer calculates his steel stress as being higher than it is when the load is first applied, but as creep continues the actual conditions approach those assumed.

Cracks

In a normal reinforced-concrete beam under load, microscopic cracks are formed long before they can be seen by the naked eye, the steel preventing the localisation of the cracks. The result is that when the cracks become visible the tensile strength of the concrete has been passed for some time. The following calculation, whilst not strictly accurate, indicates what happens. Consider a simple beam, and assume that the steel and the concrete remain attached. For a tensile stress of 18,000 lb. per square inch in the steel, the tensile stress in the concrete will be :—

$$\frac{18{,}000}{m} = \frac{18{,}000}{18} = 1{,}000 \text{ lb. per square inch.}$$

Even a strong concrete would fail at half this value, so it is clear that the concrete must have cracked and thrown the whole of the load on to the steel. Ordinarily these cracks will be distributed along the bar, and will not be seen by the naked eye.

Adhesion

It is essential that there should be a good bond between the steel and the concrete. If the steel in a beam fitted loosely in holes cast in the concrete, the strength of the beam would be little greater than if the rods were omitted, because the steel and the concrete could move independently.

Let p = perimeter of bar.
l = length of bar.
t = working tensile stress in steel.
Ab = sectional area of bar.
g = safe bond stress.

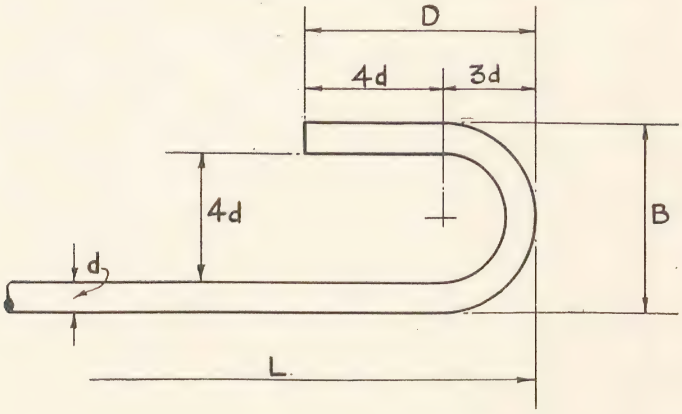


Fig. 1 (*left*).—PROPORTIONS FOR HOOKS

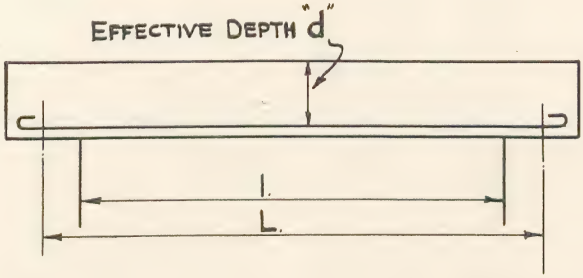
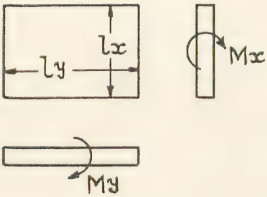


Fig. 2 (*right*). — EFFECTIVE SPAN FOR BEAMS AND SLABS



$$M_x = Z_x \frac{w l_x^2}{8}$$

$$M_y = Z_y \frac{w l_y^2}{8}$$

M_x AND M_y = BENDING MOMENTS ON STRIPS OF UNIT WIDTH AND SPANS l_x AND l_y RESPECTIVELY

w = LOAD PER UNIT AREA

l_y = LONG SIDE

l_x = SHORT SIDE

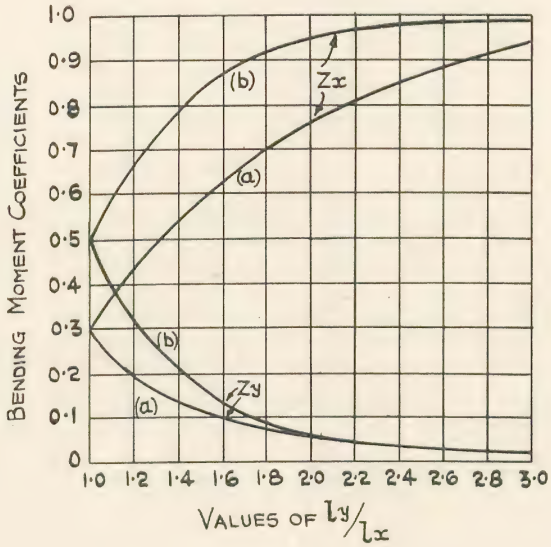


Fig. 3.—BENDING MOMENT COEFFICIENTS FOR SLABS

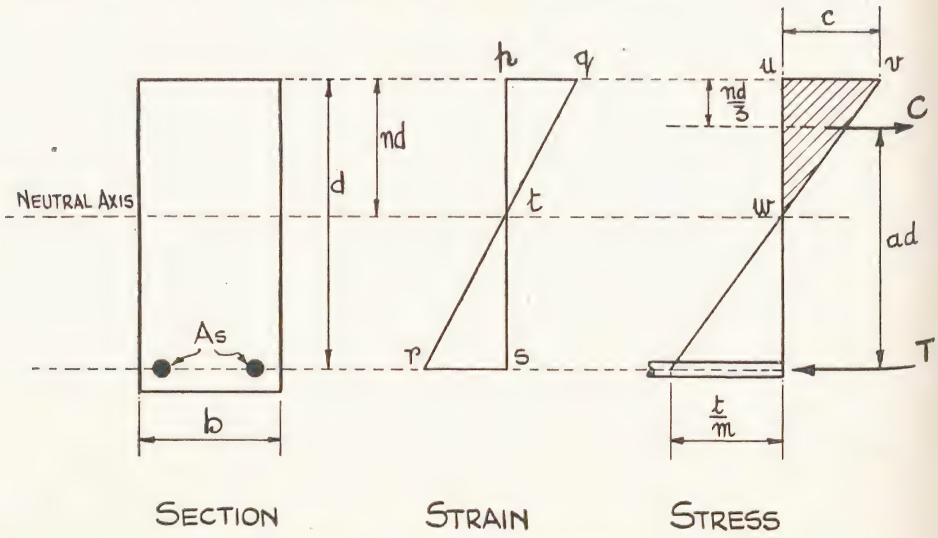


Fig. 4.—RECTANGULAR SECTION

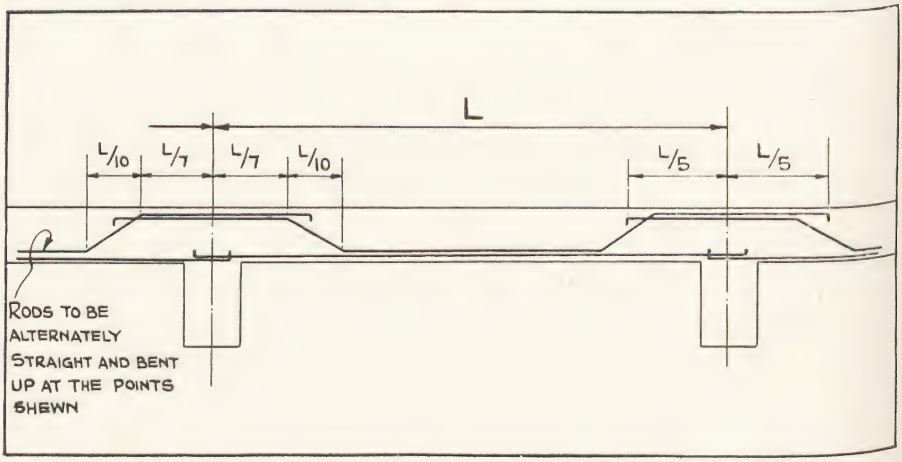


Fig. 5.—ARRANGEMENT OF STEEL IN SLAB

To reach the safe tensile stress, total load $= t \,.\, Ab$.
To reach the safe bond stress, total load $= g \,.\, l \,.\, p$.

$$t \,.\, Ab = g \,.\, l \,.\, p.$$

$$l = \frac{t}{g} \cdot \frac{Ab}{p}.$$

For a round or square bar, $\frac{Ab}{p} = \frac{d}{4}$, where d = diameter of round bar or side of square bar.

$$\text{Therefore, } l = \frac{t}{g} \cdot \frac{d}{4}.$$

For mild steel and 4 : 2 : 1 concrete (ordinary grade)—

$$l = \frac{18{,}000}{100} \times \frac{d}{4} = 45d.$$

This means that the bar should be embedded for a length equal to 45 diameters if the desired working stress of 18,000 lb. per square inch is to be reached. It will be clear from the above that the "adhesion length" depends only on the diameter of the bar, for any given stresses. The smaller the bar the shorter the "grip length," so that for a given cross-sectional area of steel the adhesion may be increased by the use of smaller bars.

Cover of Concrete and Spacing of Bars

The cover of constructional concrete measured from the outside of all reinforcing bars, including transverse ties, spirals, stirrups, and all secondary reinforcement, shall at all points be at least $\frac{1}{2}$ in. or the diameter of the bar, whichever is the greater. For main reinforcing bars in beams or columns such cover shall be at least 1 in. or the diameter of the bar, whichever is the greater.

The minimum lateral distance between reinforcing bars shall be the diameter of the bar or $\frac{1}{4}$ in. more than the maximum size of coarse aggregate, whichever is the greater, and at points of splice the bars shall be so disposed that this distance is maintained between each pair of lapped bars and adjacent bars. The vertical distance between horizontal main reinforcing bars shall be at least $\frac{1}{2}$ in. except at splices or where transverse bars are in contact. The pitch of bars or wires of main tensile reinforcement in beams and slabs shall not exceed 12 in. or twice the effective depth, whichever is the less. The pitch of distributing bars in slabs shall not exceed four times the effective depth of the slab. All meshed reinforcement shall be of such dimensions as will enable the coarse material in the concrete to pass easily through the meshes of such reinforcement.

Bar Sizes

The diameter of any reinforcing bar shall not exceed 2 in. The diameter of any reinforcing bar, including transverse ties, spirals, stirrups,

TABLE IV.—AREAS OF ROUND BARS

Diameter in Inches	Area in Square Inches	Weight per Ft. Run, Lb.	Sectional Area in Square Feet of Steel per Foot Width of Section when spaced at :														
			1½ in.	2 in.	2½ in.	3 in.	3½ in.	4 in.	4½ in.	5 in.	5½ in.	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.
¼	·049	·167	·39	·29	·23	·20	·17	·15	·13	·12	·11	·10	·08	·07	·07	·06	·05	·05
5/16	·077	·261	·61	·46	·36	·31	·26	·23	·20	·18	·17	·15	·13	·11	·10	·09	·08	·08
3/8	·110	·376	·88	·66	·53	·44	·38	·33	·29	·26	·24	·22	·19	·17	·15	·13	·12	·11
7/16	·150	·511	1·21	·90	·72	·60	·51	·45	·40	·36	·33	·30	·26	·23	·20	·18	·16	·15
½	·196	·668	1·57	1·18	·94	·78	·67	·59	·52	·47	·43	·39	·34	·29	·26	·24	·21	·20
9/16	·307	1·043	2·46	1·84	1·47	1·23	1·05	·92	·82	·74	·67	·61	·53	·46	·41	·37	·34	·31
⅝	·442	1·502	3·54	2·65	2·12	1·77	1·51	1·32	1·18	1·06	·96	·88	·76	·66	·59	·53	·48	·44
¾	·601	2·044	4·81	3·61	2·88	2·40	2·06	1·80	1·60	1·44	1·31	1·20	1·03	·90	·80	·72	·63	·60
⅞	·785	2·670	6·28	4·71	3·77	3·14	2·69	2·36	2·09	1·88	1·71	1·57	1·35	1·18	1·05	·94	·86	·78
1	·994	3·380	7·95	5·96	4·77	3·98	3·41	2·98	2·65	2·39	2·17	1·99	1·70	1·49	1·33	1·19	1·08	·99
1⅛	1·227	4·172	9·80	7·36	5·89	4·91	4·21	3·68	3·27	2·95	2·68	2·45	2·10	1·84	1·64	1·47	1·30	1·23
1¼	1·485	5·049	11·90	8·91	7·12	5·94	5·09	4·45	3·96	3·56	3·24	2·97	2·55	2·23	1·98	1·78	1·60	1·48
1⅜	1·767	6·008	14·10	10·60	8·48	7·07	6·06	5·30	4·71	4·24	3·86	3·53	3·03	2·65	2·36	2·12	1·90	1·77

and all secondary reinforcement, shall be at least $\frac{3}{16}$ in. The diameter of main reinforcing bars in beams and slabs shall be at least $\frac{1}{4}$ in. The diameter of longitudinal reinforcing bars in columns shall be at least $\frac{1}{2}$ in. The diameter of wires under tensile stress in connected mesh and similar reinforcement in slabs shall be at least $\frac{1}{10}$ in.

Bends and Hooks

The internal radius expressed in bar diameters of a bend in a reinforcing bar shall not be less than the value obtained by dividing the stress in the steel at the commencement of the bend by four times the permissible stress in the concrete in direct compression where the minimum concrete cover is used, and not less than two-thirds this value where conditions are such that there is no danger of splitting the concrete. Table V gives the values of the radii for concrete of ordinary grade.

A hook at the end of a bar shall be of ⊃ form and shall have an inner diameter of at least four times the diameter of the bar ; except that when the hook fits over a main reinforcing bar the diameter of the hook may be equal to the diameter of such bar. The length of the straight part beyond the end of the curve to the end of the hook shall be at least four times the diameter of the bar forming the hook. Unless suitable wrapping or other reinforcement is provided, the anchorage value of the hook shall not be taken into account if

TABLE V.—RADII IN BAR DIAMETERS FOR BENDS IN BARS

$$\text{Radius} = \frac{\text{stress in steel in lb. per sq. in.}}{4 \times \text{direct stress in concrete in lb. per sq. in.}}$$

Concrete Mix	*Direct Stress, Lb. per Sq. In.*	*Stress in Steel, Lb. per Sq. In.*								
		9,000	10,000	12,000	14,000	16,000	18,000	20,000	22,500	25,000
Ordinary Grade										
1 : 1 : 2	780	3*d*	4*d*	4*d*	5*d*	6*d*	6*d*	7*d*	8*d*	8*d*
1 : 1·2 : 2·4	740	4*d*	4*d*	5*d*	5*d*	6*d*	7*d*	7*d*	8*d*	9*d*
1 : 1·5 : 3	680	4*d*	4*d*	5*d*	6*d*	6*d*	7*d*	8*d*	9*d*	10*d*
1 : 2 : 4	600	4*d*	5*d*	5*d*	6*d*	7*d*	8*d*	9*d*	10*d*	11*d*
High Grade										
1 : 1 : 2	1,000	3*d*	3*d*	3*d*	4*d*	4*d*	5*d*	5*d*	6*d*	7*d*
1 : 1·2 : 2·4	960	3*d*	3*d*	4*d*	4*d*	5*d*	5*d*	6*d*	6*d*	7*d*
1 : 1·5 : 3	880	3*d*	3*d*	4*d*	4*d*	5*d*	6*d*	6*d*	7*d*	8*d*
1 : 2 : 4	760	3*d*	4*d*	4*d*	5*d*	6*d*	6*d*	7*d*	8*d*	9*d*

TABLE VI.—ALLOWANCES FOR HOOKS
(*See Fig.* 1)

Diameter of Bar. (*d*)	*B*	*D*	*Amount to be added to L*	
			For One Hook	*For Two Hooks*
$\frac{1}{2}$ in.	3 in.	$3\frac{1}{2}$ in.	5 in.	9 in.
$\frac{5}{8}$ in.	$3\frac{3}{4}$ in.	$4\frac{3}{8}$ in.	6 in.	12 in.
$\frac{3}{4}$ in.	$4\frac{1}{2}$ in.	$5\frac{1}{4}$ in.	7 in.	14 in.
$\frac{7}{8}$ in.	$5\frac{1}{4}$ in.	$6\frac{1}{8}$ in.	8 in.	16 in.
1 in.	6 in.	7 in.	9 in.	18 in.
$1\frac{1}{8}$ in.	$6\frac{3}{4}$ in.	$7\frac{7}{8}$ in.	10 in.	20 in.
$1\frac{1}{4}$ in.	$7\frac{1}{2}$ in.	$8\frac{3}{4}$ in.	12 in.	23 in.
$1\frac{3}{8}$ in.	$8\frac{1}{4}$ in.	$9\frac{5}{8}$ in.	13 in.	25 in.
$1\frac{1}{2}$ in.	9 in.	$10\frac{1}{2}$ in.	14 in.	27 in.

the hook is employed in a place where there is a danger of splitting the concrete.

LOADS

Dead Loads

A structure has to carry its own weight, which is termed "dead load," and a superimposed load or loads, known as "live load." The weight of reinforced concrete may be taken as 144 lb. per cubic foot—rather low, but convenient for purposes of calculation, and not likely to lead to any serious error. Other dead loads include any permanent weights carried by a member, such as: surfacings; walls and superstructure of concrete, masonry, brickwork, etc.; floor finishes; roof screedings; fixed machinery; tanks; and so on. Table VII gives some useful values, but whenever possible exact values should be obtained.

TABLE VII.—DEAD LOADS

Material	*Weight*
	lb. per cu. ft.
Dry earth filling	100
Timber	40–50
Granite, limestone	165
Sandstone	140
Ballast	100
Hollow clay tiles	45–50
	lb. per sq. ft.
Woodblock paving	30
Asphalte (1 in. thick)	12
Glass (1 in. thick)	14
Windows	5
Roofing slates	8
Roofing tiles	12
Hard core (1 in. thick)	10
Lath and plaster	8
Asbestos sheeting	4
Doors	8
Granolithic finish (1 in. thick)	12
Mortar screeding (1 in. thick)	10
Lime plaster (1 in. thick)	9
Road metalling (1 in. thick)	10

Live Loads

Strictly speaking, a " live " load is a moving load, but it is accepted practice to designate all superimposed loads as " live " loads. Live loads are produced by :—

(1) Occupancy.
(2) Accident.
(3) Elements (snow and wind).

Under the first heading there will be the loads caused by merchandise, furniture, people, machines, etc., and the nature of the occupancy will, of course, be the deciding factor. Accidental loads are covered, in general, by the figures given in the Code, but if it is known that there is a possibility of an " accidental " load during, say, the first three months only, allowance should be made for it. A truly accidental load is of unknown value, and the stresses set up may be greater than the design stresses, but possibly not great enough to cause failure.

Code Figures

For the purpose of calculating the loads on slabs, beams, etc., the values given in Table VIII shall be used. In every building scheduled for an applied loading exceeding 100 lb. per square foot a notice shall be permanently exhibited in a conspicuous position on every floor, stating the total superimposed load per square foot of floor area for which the floor has been designed (inclusive of partitions, if any).

TABLE VIII.—EQUIVALENT DEAD LOADS

Class No.	*Type of Building or Floor*	*Slabs. Lbs. per Sq. Ft. of Floor Area*	*Beams, Columns, Piers, Walls, and Foundations. Lb. per Sq. Ft. of Floor Area*
1.	Rooms used for domestic purposes, hotel bedrooms, hospital rooms and wards. . .	50	40
2.	Offices, floors above entrance floor . . .	80	50
3.	Offices, entrance floor, and floors below entrance floor	80	80
4.	Churches, schools, reading-rooms, art galleries, and the like	80	70
5.	Retail shops and garages for cars of not more than 2 tons dead weight	80	80
6.	Assembly halls, drill halls, dance halls, gymnasia, light workshops, public spaces in hotels and hospitals, staircases and landings, theatres, cinemas, restaurants, and grandstands . .	100	100
7.	Warehouses, book stores, stationery stores, and similar uses, together with garages for motor vehicles exceeding 2 tons dead weight; actual load to be calculated, but not less than	200	200
	Roofs	*Lb. per Sq. Ft. of Covered Area*	*Lb. per Sq. Ft. of Covered Area*
8.	Flat roofs, and roofs inclined at an angle with the horizontal of not more than 20° . . .	50	30

Slabs and Beams

The possibility of heavy local loading is covered by a list of minimum loads, given in Table IX.

TABLE IX.—ALTERNATIVE MINIMUM LOADS

Class of Floor	*Alternative Minimum Superimposed Load*	
	Slabs	*Beams*
Floors scheduled under Class 1 . .	$\frac{1}{4}$ ton uniformly distributed per ft. width.	$\frac{1}{4}$ ton uniformly distributed.
All floors under Classes 2 to 7 except garage floors under Class 7	$\frac{3}{8}$ ton uniformly distributed per ft. width.	2 tons uniformly distributed.
Garage floors under Class 7 . . .	1·5 × maximum wheel load but not less than 1 ton considered distributed over a floor area of 2 ft. 6 in. square.	

In the case of slabs, the alternative superimposed load, where specified as per foot width, shall be taken on a length equal to the span in the case of slabs spanning in one direction, and equal to the shorter span in the case of slabs spanning in two directions at right angles.

The reactions due to these alternative loads need not be allowed for in calculating the loads on columns, piers, walls, or foundations.

Columns

When designing the columns of a building it is customary to assume that all the floors will not be loaded to their full capacity at the same time. For the purpose of calculating the total load to be carried on columns, piers, walls, and foundations in buildings of more than two storeys in height, the superimposed loads for the roof and topmost storey shall be calculated in full in accordance with the schedule of loading, but for the lower storeys a reduction of the superimposed loads may be allowed in accordance with the following Table :—

TABLE X.—REDUCTIONS FOR COLUMN LOADS

Storey	*Reduction*
Next storey below topmost storey . .	10 per cent. of its superimposed load.
Next storey below	20 per cent. of its superimposed load.
Next storey below	30 per cent. of its superimposed load.
Next storey below	40 per cent. of its superimposed load.
Each succeeding storey	50 per cent. of its superimposed load.

The above reduction may be made by estimating the proportion of floor area carried by each foundation, column, pier, and wall. No such reductions shall be allowed on any floor schedules for an applied loading exceeding 100 lb. per square foot.

BENDING MOMENTS AND SHEARING FORCES

Beams and Slabs Spanning in One Direction

In order to estimate the bending moment on a beam or slab, the effective span and the whole load on the effective span shall be taken into account. The bending moments to be provided for at every cross-section shall be the maximum positive and negative moments at such cross-section for the following conditions of loading :—

(1) Alternate spans loaded and all other spans unloaded.

(2) Adjacent spans loaded and all other spans unloaded. Nevertheless, provided that the maximum positive moments so obtained in any two adjacent spans are increased by an amount not exceeding 15 per cent. of the maximum intermediate support moment, this latter may be reduced by the same amount and the bending moment curves adjusted accordingly.

The effective span of a beam or slab shall be taken as the distance between the main vertical sides of the supporting members plus the effective depth of the beam or slab at the supports, or the span between the centres of the necessary bearing surfaces, whichever is the less. See Fig. 2.

The bending moments in beams and slabs spanning in one direction shall be calculated on one of the following assumptions :—

(1) Beams may be considered as members of a continuous framework

with monolithic connection between beams and columns, and the maximum bending moments calculated taking into account the resistance of the columns to bending.

(2) Beams and slabs may be considered as continuous over supports about which they can freely rotate. Where beams frame into external columns they shall be designed to resist a negative bending moment equal to the sum of the bending moments in the upper and lower columns.

(3) Unless more exact estimates are made, the total bending moments in cases of uniformly distributed loading over a number of approximately equal spans may be assumed to have the following values :—

Near Middle of End Span	*At Support next to End Support*	*At Middle of Interior Spans*	*At Other Interior Supports*
$+\frac{Wl}{10}$	$-\frac{Wl}{10}$	$+\frac{Wl}{12}$	$-\frac{Wl}{12}$

where W = total load (i.e. sum of dead and superimposed loads) on the beam or slab ;

and l = effective span of the beam or slab.

It must be realised that the approximate formulæ in (3) should be used only when the spans are equal or nearly so. Special care should be taken when a short span comes between two long ones, as is often the case in schools where a corridor runs between two rows of classrooms. In such a case the moment will be negative across the whole of the short span, and it would be wise to include top steel.

TABLE XI.—BENDING MOMENT COEFFICIENTS FOR SLABS SPANNING IN TWO DIRECTIONS AT RIGHT ANGLES

$$Mx = zx\frac{wlx^2}{8}; \qquad My = zy\frac{wly^2}{8},$$

where Mx and My = bending moments to be taken on strips of unit width, and of effective spans lx and ly respectively,

w = total load per unit area,

and zx and zy = coefficients.

Case (a)

ly/lx	1·0	1·1	1·2	1·3	1·4	1·5	1·75	2·0	2·5	3·0
zx	0·295	0·358	0·419	0·477	0·532	0·581	0·681	0·757	0·869	0·940
zy	0·295	0·237	0·191	0·154	0·127	0·107	0·071	0·051	0·032	0·022

Case (b)

ly/lx	1·0	1·1	1·2	1·3	1·4	1·5	1·75	2·0	2·5	3·0
zx	0·500	0·594	0·675	0·741	0·794	0·835	0·904	0·941	0·975	0·988
zy	0·500	0·406	0·325	0·259	0·206	0·165	0·096	0·059	0·032	0·022

Slabs Spanning in Two Directions at Right Angles

(1) *Slabs simply supported on four sides.*—Where the corners of the slab are prevented from lifting and adequate provision is made, by special reinforcement at the top and bottom or otherwise, to resist torsion at the corners of the slab, the bending moments at the centre of a uniformly loaded simply supported slab may be assumed to have the values given in Table XI, case (*a*), and shown by curves (*a*) in Fig. 3. Where such provision is not made, the bending moments shall be assumed to have the values given in Table XI, case (*b*), and shown by curves (*b*) in Fig. 3.

(2) *Slabs fixed at or continuous over four sides.*—The values given in Table XI, case (*a*), and Fig. 3, curves (*a*), may be reduced by 20 per cent. when the slab is fixed at or continuous over the four sides, provided that the negative bending moments to be provided for at the supports shall be equal to the values obtained from case (*a*) without reduction.

SLABS

Rectangular Section with Tension Steel only

Let

b = breadth of section.
d = effective depth of section.
As = area of steel.
ps = percentage of steel.
nd = depth of neutral axis.
Es = modulus of elasticity of steel.
Ec = modulus of elasticity of concrete.
t = tensile stress in steel.
c = maximum fibre stress in concrete.
m = modular ratio.
ad = lever arm.
M = moment of resistance.
T = total tension.
C = total compression.
R = factor showing the moment of resistance.

By definition—

$$ps = \frac{100\ As}{b\,.\,d}.$$

From the diagram of strains, by similar triangles—

$$\frac{\text{Strain on steel}}{\text{(Max.) strain on concrete}} = \frac{rs}{pq} = \frac{st}{pt} = \frac{1-n}{n}.$$

$$\frac{\text{Strain on steel}}{\text{Stress on steel}} = \frac{rs}{t} = \frac{1}{Es}.$$

$$\text{Strain on steel} = \frac{t}{Es}.$$

$$\text{Similarly, strain on concrete} = \frac{c}{Ec}.$$

$$\text{Therefore, } \frac{\text{strain on steel}}{\text{strain on concrete}} = \frac{t}{c} \times \frac{Ec}{Es} = \frac{t}{c} \times \frac{1}{m}.$$

$$\text{So that } \frac{m\,(1-n)}{n} = \frac{t}{c}.$$

$$\text{Total tension } T = As \times t = As \,.\, c \,.\, \frac{m\,(1-n}{n}).$$

From the diagram of stresses, total compression is represented by triangle *uvw*.

$$\text{Total compression } C = \frac{b \,.\, uv \,.\, wu}{2} = \frac{b \,.\, c \,.\, nd}{2}.$$

As the section is resisting only a bending moment,

$$\text{Total tension} = \text{total compression}$$

$$As \,.\, c\, \frac{m\,(1-n)}{n} = \frac{b \,.\, c \,.\, nd}{2}.$$

$$\text{Putting in the value } As = \frac{ps \,.\, b \,.\, d}{100},$$

$$\text{we get } ps = \frac{50}{m} \cdot \frac{n^2}{(1-n)}.$$

This shows that the depth of the neutral axis depends on the percentage of steel and the modular ratio.

The moment of resistance, which equals the applied bending moment, is the total tension (or compression) multiplied by the lever arm (the distance between the two lines of action of the forces).

$$M = C \,.\, ad = \frac{c \,.\, b \,.\, nd}{2}\left(d - \frac{nd}{3}\right)$$

$$= R \,.\, bd^2,$$

$$\text{where } R = \frac{c}{2}\, n\left(1 - \frac{n}{3}\right).$$

$$\text{Also, } M = T \,.\, ad = \frac{ps \,.\, b \,.\, d \,.\, t}{100}\left(d - \frac{nd}{3}\right)$$

$$= R \,.\, bd^2,$$

$$\text{where } R = \frac{ps \,.\, t}{100}\left(1 - \frac{n}{3}\right).$$

If there is a very small area of steel the value of t will be passed before c reaches its allowable maximum. An increasing moment on such a section would cause the steel to fail by tension. If, on the other hand, there is a large amount of steel, the concrete would reach its maximum stress before the steel, so that such a beam would fail by crushing of the concrete. Clearly, there is a critical point where the concrete and steel

TABLE XII.—BENDING COEFFICIENTS

Grade of Concrete	*Nominal Concrete Mix*	*Permissible Stress in Bending* (x) *Lb. per Sq. In.*	*Modular Ratio* m = $\frac{(40{,}000)}{3x}$	18,000 *Lb. per Sq. In. Steel Stress* n = 0·42553 a = 0·85816		20,000 *Lb. per Sq. In. Steel Stress* n = 0·40000 a = 0·86667		25,000 *Lb. per Sq. In. Steel Stress* n = 0·34782 a = 0·88406	
				Economic Percentage (0·0011820 x)	$R\left(=\frac{M}{bd^2}\right)$ (0·18258 x)	*Economic Percentage* (0·0010000 x)	$R\left(=\frac{M}{bd^2}\right)$ (0·17333 x)	*Economic Percentage* (0·00069564x)	$R\left(=\frac{M}{bd^2}\right)$ (0·153747 x)
Ordinary grade	1 : 1 : 1	975	13·68	1·153	178·0	0·975	169·0	0·678	149·9
	1 : 1·2 : 2·4	925	14·41	1·093	168·9	0·925	160·3	0·644	142·2
	1 : 1·5 : 3	850	15·69	1·005	155·2	0·850	147·3	0·591	130·7
	1 : 2 : 4	750	17·78	0·887	136·9	0·750	130·0	0·522	115·3
High grade	1 : 1 : 2	1250	10·67	1·478	228·2	1·250	216·7	0·870	192·2
	1 : 1·2 : 2·4	1200	11·11	1·418	219·1	1·200	208·0	0·835	184·5
	1 : 1·5 : 3	1100	12·12	1·300	200·8	1·100	190·7	0·765	169·1
	1 : 2 : 4	950	14·03	1·123	173·5	0·950	164·7	0·661	146·1
Special grade	1 : 1 : 2	1563	8·53	1·848	285·4	1·563	270·9	1·087	240·3
	1 : 1·2 : 2·4	1500	8·89	1·773	273·9	1·500	260·0	1·044	230·6
	1 : 1·5 : 3	1375	9·70	1·625	251·1	1·375	238·3	0·957	211·4
	1 : 2 : 4	1188	11·22	1·404	216·9	1·188	205·9	0·826	182·7

will reach the maximum stresses simultaneously. The amount of steel required for this condition is referred to as the "economic" percentage.

We have seen that $\frac{t}{c} = \frac{m(1-n)}{n}$.

For the economic percentage, substituting $m = \frac{40{,}000}{3c}$,

$$\frac{40{,}000}{3t} = \frac{n}{1-n}.$$

From this, $$n = \frac{40{,}000}{3t + 40{,}000}.$$

Therefore, for the economic percentage the depth to the neutral axis is the same for all mixes and grades, the value depending merely on the allowable steel stress.

The values of R and *ps* have been worked out by Scott and Glanville for various mixes, and are given in Table XII. It will be found convenient to draw a series of graphs similar to the one shown in Fig. 6.

In Fig. 6 it will be seen that below the critical point the strength of the steel limits the strength of the slab or beam, the concrete not being fully stressed. Above this point, the concrete is the determining factor.

Graphs similar to Fig. 7 should also be drawn, as they will be found to save a lot of calculation.

Example of Slab Design

Roof slab, 8-ft. effective span, interior span.

$\frac{3}{4}$-in. asphalte	8 lb.	per square foot
Screeding	14 lb.	,, ,, ,,
Ceiling	6 lb.	,, ,, ,,
$3\frac{1}{2}$-in. slab—$(3\frac{1}{2} \times 12)$ . .	$\frac{42}{70}$ lb.	,, ,, ,,
Live load	$\frac{50}{120}$ lb.	,, ,, ,,

$$\text{B.M.} = \frac{Wl}{12}$$

$$= 7{,}680 \text{ in. lb.}$$

Effective depth is $(3\frac{1}{2} \text{ in.} - \frac{3}{4} \text{ in.}) = 2{\cdot}75$ in.

$$R = \frac{\text{B.M.}}{b \cdot d^2} = \frac{7{,}680}{12 \times 2{\cdot}75 \times 2{\cdot}75}$$

$$= 85.$$

This is below the critical point on the graph, so that the steel governs the strength.

$$As = \frac{\text{B.M.}}{t \times ad}$$

$$= \frac{7{,}680}{18{,}000 \times 0{\cdot}858 \times 2{\cdot}75} = 0{\cdot}181 \text{ sq. in.}$$

Use $\frac{5}{16}$-in. diameter bars at 5-in. centres = 0·18 sq. in.
Actually a would only have the value 0·858 at the economical percentage, but the slight error is usually of no significance. When the percentage of steel has been found, a revised calculation can be made if required, using a new value for a.

Distributing bars shall have a total area of at least 20 per cent. of the main steel, and the pitch of the bars shall not be more than four times the effective depth of the slab. It will be convenient, then, to use $\frac{1}{4}$-in. diameter bars at 11-in. centres, = 0·05 sq. in.

The main steel could be arranged as shown in Fig. 5. Bending up alternate rods gives the same area of steel over the supports as in the middle of the span.

Resisting Moments

In Table XIII are given the resisting moments (calculated by W. E. J. Budgen) of eleven slabs having approximately the economic percentage of steel.

BEAMS

General

The design of beams is similar to the above, but it is necessary to take into consideration other points such as flanged beams, double reinforcement, and shear.

Beams shall be secured laterally whenever the ratio of the length of the beam to the width of its compression flange exceeds—

$$20 \left(3 - 2 \times \frac{\text{calculated compressive stress}}{\text{permissible compressive stress}} \right)$$

When the two stresses are equal the laterally unsupported length may be twenty times the width of the beam.

Compression Reinforcement

In cases where the compressive resistance of the concrete is taken into account the compression reinforcement shall be effectively anchored over the distance where it is required at points not farther apart (centre to centre) than twelve times the diameter of the anchored bar. In cases where the compressive resistance of the concrete is not taken into account the compression reinforcement shall be effectively anchored laterally and vertically over the distance where it is required at points not farther apart (centre to centre) than eight times the diameter of the anchored bar. The subsidiary reinforcement used for this purpose shall pass round or be hooked over both the compression and tension reinforcement.

TABLE XIII.—RESISTING MOMENTS

(18,000 lb. per square inch and 750 lb. per square inch)

Thickness of Slab, Inches	*Reinforcement*				*Resisting Moment, In. lb.*
	Main		*Distribution*		
	Diameter, Inches	*Centres, Inches*	*Diameter, Inches*	*Centres, Inches*	
3	$\frac{5}{16}$	$3\frac{1}{2}$	$\frac{1}{4}$	9	9,000
$3\frac{1}{2}$	$\frac{3}{8}$	$4\frac{1}{2}$	$\frac{1}{4}$	9	13,000
4	$\frac{3}{8}$	$3\frac{3}{4}$	$\frac{5}{16}$	12	18,000
$4\frac{1}{2}$	$\frac{1}{2}$	6	$\frac{3}{8}$	15	23,000
5	$\frac{1}{2}$	5	$\frac{3}{8}$	14	29,000
$5\frac{1}{2}$	$\frac{5}{8}$	$7\frac{1}{2}$	$\frac{7}{16}$	18	34,000
6	$\frac{5}{8}$	$6\frac{3}{4}$	$\frac{1}{2}$	20	42,000
$6\frac{1}{2}$	$\frac{5}{8}$	6	$\frac{1}{2}$	18	50,000
7	$\frac{5}{8}$	$5\frac{1}{2}$	$\frac{5}{8}$	24	60,000
$7\frac{1}{2}$	$\frac{3}{4}$	$7\frac{1}{2}$	$\frac{5}{8}$	24	66,000
8	$\frac{3}{4}$	7	$\frac{5}{8}$	24	77,000

Flanged Beams

Where in T-beams the slab takes the compression, its breadth shall not be taken to exceed the least of the following :—

(*a*) One-third of the effective span of the T-beam ;

(*b*) The distance between the centres of the ribs of the T-beams ;

(*c*) The breadth of the rib plus twelve times the thickness of the slab.

Where in L-beams the slab takes the compression, its breadth shall not be taken to exceed the least of the following :—

(*a*) One-sixth of the effective span of the L-beam ;

(*b*) The breadth of the rib plus one-half the clear distance between the ribs.

(*c*) The breadth of the rib plus four times the thickness of the slab.

The reinforcement in that portion of slab required to take the compression in a T- or L-beam shall extend its full width and shall consist of bars transverse to the beam. Such reinforcement shall not be less than 0·3 per cent. of the total cross-sectional area of the slab, and in cases where the slab is assumed to be independently spanning in the same direction as the beam such reinforcement shall be near the top surface of the slab.

Shear

The shear stress s at any cross-section in a reinforced-concrete beam or slab shall be calculated from the equation—

$$s = \frac{S}{b \,.\, ad}$$

where S = total shear across any section ;
b = breadth of rectangular beam or breadth of rib of T-beam ;
and ad = arm of resistance moment.

Where at any cross-section the value of the shear stress, as calculated from the equation above, does not exceed the permissible shear stress for plain concrete, no shear reinforcement need be provided.

Where at any cross-section the value of the shear stress, as calculated from the equation above, exceeds the permissible shear stress for plain concrete, the whole shear at such cross-section shall be provided for by the tensile resistance of the shear reinforcement acting in conjunction with the diagonal compression of the concrete in the web. In no case shall the shear stress calculated from the equation exceed four times the permissible shear stress for plain concrete.

The shear or web reinforcement shall pass round the tensile reinforcement or be otherwise secured thereto and shall be effectively anchored at both ends in such a manner that its full working stress can be developed. Tensile reinforcement which is inclined across the neutral plane of a beam and which is carried through a depth equal to the arm of the resistance moment may be taken as shear or web reinforcement, providing it is effectively anchored. Where two or more types of web reinforcement are used in conjunction, the total shearing resistance of the beam shall be assumed as the sum of the shearing resistances computed for the various types separately. The spacing of stirrups shall not exceed a length equal to the arm of the resistance moment. The resistance to shear, S, shall then be calculated from the equation—

$$S = \frac{tw \,.\, Aw \,.\, ad}{p}$$

where tw = permissible tensile stress allowed in shear or web reinforcement ;
Aw = cross-sectional area of stirrup ;
p = pitch or spacing of stirrups ;
and ad = arm of resistance moment.

The resistance to shear at any section of a beam reinforced with bent-up bars may be calculated on the assumption that the bent-up bars form the tension members of one or more single systems of lattice girders in which the concrete forms the inclined compression members. The shear resistance at any vertical section shall then be taken as the sum of the vertical components of the inclined tension and compression forces cut by such section. Where on these assumptions the force required for equilibrium in the horizontal portion of a bar is greater than the force in the inclined portion (that is, wherever the angle between the inclined compression and the longitudinal axis of the beam is less than half the angle between the inclined and horizontal portions of the bar), the force in the inclined bar shall be limited to a value such that the permissible stress in the steel is not exceeded in the horizontal portion.

COLUMNS

The Code gives a new method of designing columns. Let—

P = axial load on a short column reinforced with longitudinal bars and lateral ties ;

c = permissible direct stress on concrete ;

t = permissible stress for longitudinal steel in direct compression ;

Ac = area of concrete ;

As = area of longitudinal steel :

$$P = c \cdot Ac + t \cdot As.$$

Example

Design a column to carry 88 tons, using mild steel and high-grade concrete having a 4 : 2 : 1 mix.

t = 13,500 lb. per square inch.

c = 760 lb. per square inch.

Longitudinal reinforcement must not be less than 0·8 per cent. nor more than 8 per cent. of the concrete area.

Assume a square section of side x with 1 per cent. of steel.

Steel area is $0{\cdot}01x^2$.

Concrete area is $0{\cdot}99x^2$.

Safe load = $(760 \times 0{\cdot}99x^2) + (13{,}500 \times 0{\cdot}01x^2)$ lb.

= 88 tons.

x = 15 in.

1 per cent. of concrete area is 2·25.

4 bars $\frac{7}{8}$ in. = 2·41 sq. in.

Use a column 15 in. × 15 in., with four bars $\frac{7}{8}$-in. diameter.

Lateral Ties

The volume of transverse reinforcement must not be less than 0·4 per cent. of the gross volume of the column. The pitch of lateral ties shall be not more than 12 in. and not less than 6 in. Also, the pitch must not be greater than the width of the column, and not greater than twelve times the diameter of the longitudinal bars. In this case, then, the limits for the pitch are 6 in. and 10½ in. Where the pitch is the maximum permitted, the diameter of the tie shall be at least one-quarter of the largest longitudinal bar secured by it.

Spiral Reinforcement

Spiral reinforcement shall consist of evenly spaced spirals, and shall have its ends anchored. The pitch of the spirals shall not be more than 3 in. or one-sixth of the diameter of the core, whichever is the less, and shall not be less than 1 in. or three times the diameter of the bar composing the spiral, whichever is the greater.

Where spiral reinforcement is used, the axial load P on the column shall not exceed the value given by (1) or (2) below, whichever is the greater.

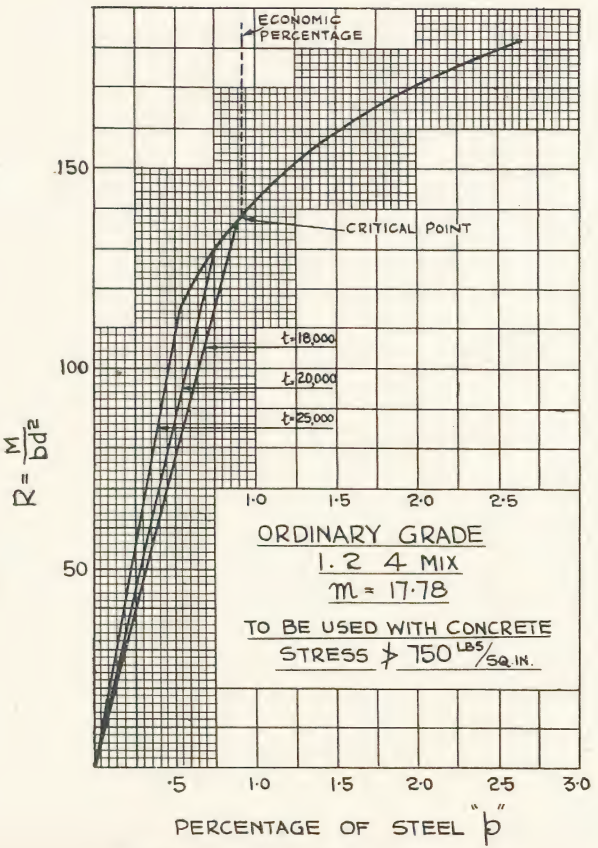


Fig. 6.—RELATION BETWEEN R AND ps

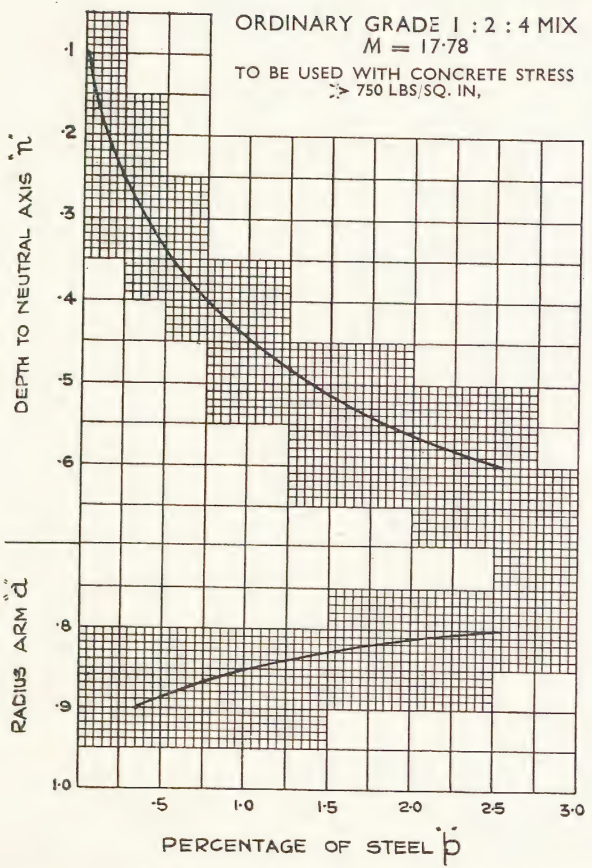


Fig. 7.—RELATION BETWEEN n AND p AND BETWEEN a AND p

$$P = cA_c + tA \quad . \quad . \quad . \quad . \quad (1)$$

where c = permissible direct stress for concrete ;
t = permissible stress for longitudinal steel in direct compression ;
A_c = cross-sectional area of concrete not including any finishing material applied after the casting of the column ;
and A = cross-sectional area of longitudinal steel.

$$P = cA_k + tA + 2{\cdot}0\ t_bA_b \quad . \quad . \quad . \quad (2)$$

where A_k = cross-sectional area of concrete in the core ;
t_b = permissible stress in tension in spiral reinforcement ;
and A_b = equivalent area of spiral reinforcement (volume of spiral per unit length of the column).

In no case shall the sum of the loads contributed by the concrete in the core and by the spiral exceed $0{\cdot}5uA_c$, where u is the crushing strength of the concrete required from the works test.

FLAT SLABS

This form of construction, not recognised under the old L.C.C. regulations, has many advantages over the usual slab and beam construction :—

(1) A saving of 12 in. or more in the height required from floor to floor.
(2) Better lighting.
(3) Better ventilation.
(4) Easier arrangement of sprinklers, piping, shafting, etc.
(5) Simpler formwork.
(6) A saving in material, if the floor loads are heavy.
(7) Greater fire resistance.

To enable the system to be used, the site must be capable of being divided into approximately equal square bays with column centres from 16 to 25 ft. part. The floor planning must not require a large amount of solid partitioning or large openings in the slabs. There will be no economy over beam and girder construction for superimposed loads of less than 100 lb. per square foot. The rules for proportioning members (which are given in full in the Code) are based on the results of extensometer measurements of concrete and steel in actual buildings under test loads. Two types of construction, with and without " drop panels," are recognised. The external columns can be arranged either in the external wall, or, if an uninterrupted area of glass is required, they may be set back in the building, and the floor slabs cantilevered over them.

PRESSURE ON SUBSOILS

The following permissible loads upon various subsoils are given as a general guide to their safe bearing capacity, but the building owner shall be responsible for providing any trial holes, loading tests, or other measures necessary to ascertain the safe bearing load of the ground upon which the foundations of a building are to be bedded.

TABLE XIV.—LOADS ON GROUND

Type of Subsoil	*Permissible Load on Ground. Tons per Sq. Ft.*
Alluvial soil, made ground, very wet sand	Up to ½
Soft clay, wet or loose sand	Up to 1
Ordinary fairly dry clay, fairly dry fine sand, sandy clay	Up to 2
Firm dry clay	Up to 3
Compact sand or gravel, London blue or similar hard compact clay	Up to 4
Hard solid chalk	Up to 6
Shale and soft rock	Up to 10
Hard rock	Up to 20

Intermediate values and values for other materials shall be agreed in consultation with the local building authority. The above pressures may be exceeded by an amount equal to the weight of the material in which a foundation is bedded and which is displaced by the foundation itself, measured downward from the final finished lowest adjoining floor or ground level.

We are indebted to H.M. Stationery Office for permission to include data in the above article from the *Code of Practice*, published by them. See also page 612.

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